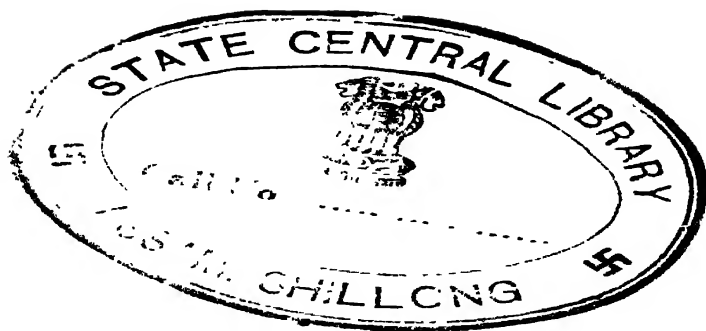


PHOTOGRAPHY
THEORY AND PRACTICE





THE AUTHOR

PHOTOGRAPHY

THEORY AND PRACTICE

The English Edition of "La Technique Photographique"

BY

L. P. CLERC, Hon. F.R.P.S.

EDITED BY

A. KRASZNA-KRAUSZ

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PREFACE

TO THE THIRD ENGLISH EDITION

L. P. CLERC'S *La Technique Photographique* was first published in 1926. It is at present in its fifth French edition. The first English edition appeared in 1930. It was the work of the late George E. Brown, Editor, 1906-1934, of the *British Journal of Photography* and an outstanding figure in this country's photographic literature. The exceptional merits of *La Technique Photographique* have been acclaimed from the outset. It was unmistakably the first comprehensive textbook of photography built on modern scientific foundations. It still represents a unique overall view of photographic theory and practice; clear in its approach, consistent in its level and precise in detail. It required encyclopaedic knowledge, a singularly versatile grasp of science and technology, besides editorial skill acquired by long experience, to accomplish such a work. These were, of course, the very qualities and qualifications L. P. Clerc brought to bear on this task.

L. P. Clerc is to-day 79 years of age; a holder of the *Croix de Guerre*, 1914-18, *Chevalier de la Legion d'honneur*, honoured with the Progress Medal of the Royal Photographic Society 1950, a Member of the *Société Française de Photographie et de Cinématographie* since 1897, and of its Council since 1923, he is also an Honorary Fellow of both the *Royal Photographic Society* and the *Photographic Society of America*. Besides his activities as a scientific consultant to industry and leader of research in peace and war, teacher, lecturer and author, he has been for over thirty years editor of *Sciences et Industries Photographiques*. The abstracts regularly published in this distinguished monthly are largely L. P. Clerc's own work and are printed from manuscripts written in a longhand as impeccably crisp as their contents excel by their brilliant clarity.

To quote an eminent younger scientist who has done much valuable work on the present English editions: "I cannot help being amazed at the depth of Clerc's understanding. In the same way that he will write a wonderfully intelligible précis of one's own rather too lengthy and abstruse paper—thus putting one thoroughly to shame—so he succeeds in presenting the theory of each of the processes described in his book in crystal-clear form." The same writer also says: "The more I have seen of this book, the more have I been impressed. It could have been written only by a man of Clerc's calibre and experience. To compile a work in this way implies having a bird's-eye view of the whole field such as none of the younger generations possess or can ever hope to possess—we are all much too specialized."

The last remark offers the key to the present English edition. A second English edition having been published in 1937, followed by five reprints, the need for revisions in the light of recent progress became urgent soon after the war. No revised French edition being as yet available at that time, the publishers accepted my recommendation to employ a panel of experts for revising the chapters that covered their respective fields of work. That no less than seventeen scientists and other writers had to lend their assistance is as obvious a confirmation of L. P. Clerc's achievement as the polyhistor of photography as was the request of the contributors not to have

their work individually acknowledged and so not encroach on the author's uniformly respected authority.

The gesture of my collaborators in wanting to remain unnamed calls for an explanation of my own functions as an editor. These were confined to planning, administering and supervising the work which I would have been quite incapable of carrying out on my own. Thus my name on the title page signifies only a formal responsibility which I felt was a duty and privilege to accept.

This new edition differs from its predecessors in some respects. Technical information has been brought up to date throughout the book; in the course of this, certain chapters—for example, those on processing and colour—have been appreciably extended. New matter has been absorbed from the latest French edition reaching this country while the English revisions were in progress. The terminology which earlier had suffered in places by translation from the French, has been brought more in step with English practice and will now be found, it is hoped, reasonably uniform. Many of the footnotes which earlier editions tended to accumulate are now incorporated in the main body of the text. The somewhat sketchy marginal chapters on cinematography and radiography, and the tabulation of historic dates have now been dropped from this English edition. A new, very detailed index has been compiled, to do fuller justice to what is—in spite of its illustrious author's protestations to the contrary—a work of truly encyclopaedic scope.

A. KRASZNA-KRAUSZ

AUTHOR'S PREFACE

To inveigh against theory, even in the most elementary arts, proves only the ignorance of the invigher. It is not the profoundness of the theory, but its imperfections, that should be blamed for the ill effects that so often follow its working out in practice. . . . Many data regarding the needs to be satisfied, the means of satisfying them, the time and expenditure involved, that are perforce ignored within the field of mere theory, come into the problem of working out a practical application. By bringing these factors into play with the skill that marks practical genius, it is possible both to extend the narrow limits within which prejudices against theorizing tend to confine the arts, and to guard against the mistakes to which an unskilful use of a particular theory may give rise.

—CONDORCET (*Tableau des Progrès de l'Esprit humain*, 1793)

THIS book does not represent an attempt to compile an encyclopaedia, a work of a kind which is always loaded with descriptions of obsolete methods and appliances and the details of numerous applications of interest only to a few technical people. The author's aim has been to bring into one volume as complete a treatise as possible on modern working methods and apparatus in conjunction with the minimum of theoretical considerations which he considers necessary for their proper understanding.

The beginner is recommended to study at first the parts of practical instruction which he requires, and to postpone a reading of the whole work until he has acquired some practical experience. In the interval he can make use of the book in the manner of a dictionary, by aid of the full alphabetical index at the end.

Objection may be taken to the absence of bibliographical references. But such references would have been exceedingly numerous and would have added considerably to the already large number of pages without much advantage to most readers.

Therefore the references have been confined to a mention of the names of the authors (and dates) of various discoveries, improvements, and experiments, a plan which at any rate will serve to narrow down the scope of any bibliographical search which some readers may wish to carry out.

The author's professional duties for thirty years past have rendered it necessary for him to read nearly everything which has been published on photography in the technical journals of the chief countries of the world, and to experiment or supervise experiments in regard to a large number of the data thus collected. In a certain measure therefore this work may be considered the work of all; and the author would excuse himself to experimenters and writers whose ideas and recommendations have been mentioned, possibly without acknowledgment.

Since the publication in 1926 of the original French edition, the author has made a considerable number of additions and corrections which are embodied in the present English translation.

The author desires to express to the translators and editor of this volume his sincere thanks for the evident care with which their work has been done. Their critical comments have enabled the author to correct several errors in the original edition.

L. P. C.

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ABBREVIATIONS

Å.	.	Angström unit (§ 2)	mm	.	millimetre
B	.	degree Baumé (hydrometer)	F	.	degree Fahrenheit
m	.	metre	g	.	gramme
C	.	degree Centigrade	gr	.	grain
cc.	.	cubic centimetre = ml	min	.	minim
cm	.	centimetre	oz	.	ounce
dram	.	dram	ml	.	millilitre = cc.

PART I

INTRODUCTION: VISION AND PHOTOGRAPHY

CHAPTER I

LIGHT AND COLOUR

1. White Light. The illuminant which is usually considered normal for both visual and photographic purposes is the so-called "white light." This can come from a number of sources or combinations of sources, but in all cases will have similar properties. If a beam of white light be passed through a prism of glass or other suitable transparent medium it will be split up into its component colours. The spectrum, or band of colours produced by the prism, can be seen to consist of three main regions, each of which blends gradually into the next, over two narrow transition regions. The three broad divisions are the blue-violet, green, and red. Between these bands occur the transition regions of blue-green and yellow. This is best seen in the spectrum formed by a diffraction grating, which does not spread out the colours unequally as does a prism but gives an evenly spaced spectrum.

Light appears white when the amounts of blue, green, and red are approximately equal. If there is one part of the spectrum which predominates then the light appears coloured.

When a spectrum is carefully examined it will be seen that the three primary divisions are purely arbitrary; the bands can be further divided, as is often done, into violet, indigo, blue, green, yellow, orange, and red. Further subdivision leads to such vague terms as bluish-green, reddish-orange, and so on. When this stage is reached it is no longer possible to specify a colour accurately by name, since the naming of colours is dependent on memory-matching, and few people have this ability. However, it is possible to identify a spectrum colour by a perfectly accurate description. Light is one of the many forms of electromagnetic radiation of a wave-form nature. Colours can therefore be specified by their wavelength or by a band of wavelengths.

2. Light Waves—Wavelength. Everyone is familiar with electromagnetic radiation in connexion with radio receivers. Other forms of electromagnetic radiation, listed in order as the

wavelength becomes shorter are—short-wave radio, radar, heat-therapy, long-wave infra-red, visible light, ultra-violet light, long-wave X-rays which penetrate only soft materials, short-wave X-rays of high penetrating power, gamma radiations, and perhaps cosmic rays from the upper atmosphere. All these are radiations in which there is an electromagnetic strain, which can be produced without any matter being present to conduct it. This is in contrast to sound waves which are purely mechanical vibrations of matter and therefore need matter to transmit them. Sound is not transmitted through a vacuum, as is electromagnetic radiation.

The wavelength of the radiation is dependent on the frequency. There is one velocity for all forms of electromagnetic radiation passing through a vacuum. As each form has its own particular frequency the wavelength is simply the velocity divided by the frequency. For example, if the velocity is 3×10^{10} metres per second and if the frequency is 6×10^{15} cycles per second, then in each of these cycles the wave must travel 0.5×10^{-6} metres and this is the wavelength. This is the wavelength of green light. The universal symbol for denoting the wavelength of light is the Greek letter λ (lambda). Wavelengths may be specified in any of several units.

As the very early researches into light radiation were of low accuracy it was not necessary to use many significant figures and in fact wavelengths were specified in microns ($\mu = 1/1,000$ mm) and the spectrum ranged from 0.4 to 0.7μ . The researches of Angström into spectroscopy opened up a field in which the wavelength of spectral lines had to be very precisely defined. As a result the Angström units ($\text{\AA} = 10^{-7}$ mm) were introduced, the spectrum ranging from $4,000$ to $7,000 \text{\AA}$. For the purposes of less accurate measurements of the wavelength of radiation it is sufficient to use a third unit, the millimicron ($m\mu = 10^{-6}$ mm), and in these the spectrum ranges from 400 to

700 $m\mu$. In Fig. 1.1 is shown the distribution of wavelengths in a linear spectrum and the colours which are commonly attached to these broad regions of the spectrum.

3. **Spectrum Lines.** The spectrum formed by dispersing either sunlight or artificial light such as that from a tungsten-filament lamp, gives a spectrum in which there is continuous gradation of colour and brightness from one end to the other. If, however, the light comes from an electric current arcing between two electrodes then we have departed from the normal method of heating up matter to make it radiate. The

In 1931 the International Committee of Illumination specified such a standard curve, based on much accurate work using the above methods. Recent researches show that this curve is not an accurate statement of fact for the blue part of the spectrum. More precise measurements have indicated a variation from the smooth curve due to pigmentation in the macular region of the retina. This is another characteristic which varies between observers. The curve for the standard observer will, however, stand for a long time yet.

The curve for daylight illumination has its

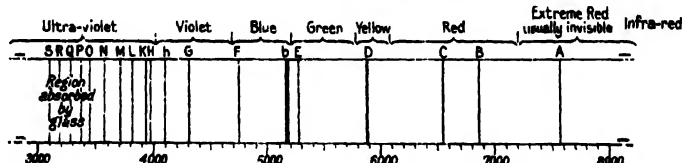


FIG. 1.1. DISTRIBUTION OF COLOURS IN THE SOLAR SPECTRUM WITH ABSORPTION (FRAUNHOFER) LINES A TO S

arc or discharge is so violent as to cause disturbance within the atomic structure of the materials. The disturbances result in the electrons increasing their energy in certain specified and well-organized ways. This condition, however, is unstable and eventually there must be a return to the former energy level. As the electron does this it radiates as light the energy which it absorbed in rising to the higher levels. This light is radiated at a given frequency and therefore has an associated wavelength. In the atomic structure there are a number of levels and interchange can go on between many of these. Each of these will produce a radiation of specific frequency.

As a result, the spectra of these sources are restricted to a number of narrow bands at particular frequencies which are characteristic of the materials used for the electrodes. These narrow bands are called spectrum lines. The photographic applications of discharge or arc sources will be dealt with later in more detail.

4. **Luminosity of Different Spectrum Colours.** If a number of people are tested so as to ensure that they are not colour-blind, it is possible, by a series of experiments, to compile a series of curves which represent the sensitivity of their eyes to different wavelengths. These graphs will differ from one to another slightly, and an average curve can be drawn. This curve can also be thought of as representing the luminosity of different spectrum colours as seen by the eye.

maximum luminosity in the yellow-green at 555 $m\mu$. At night, however, the eye functions by another mechanism; one which is not operative in daylight because the high intensities of light destroy the responsible photochemical agent. Daylight vision does not function at

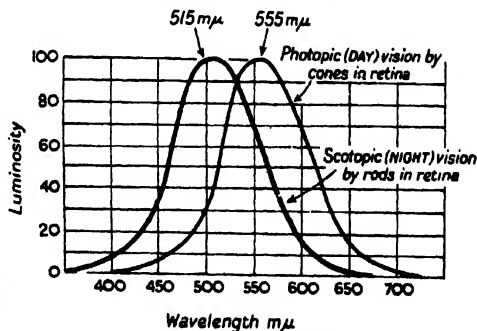


FIG. 1.2. THE LUMINOSITY CURVES OF THE EYE FOR DAY AND NIGHT VISION, SHOWING THE SHIFT IN MAXIMUM INTENSITY (Purkinje shift)

levels of brightness below that of moonlight, at which night vision takes over. Night vision has no colour sensitivity. It has a luminosity curve which is similar in shape to that of daylight vision, but the wavelength of maximum luminosity is displaced from 555 to 515 $m\mu$ (Fig. 1.2) This shift is known as the Purkinje

shift. The only significance of it in photography is that it is fully used in darkrooms where the illumination is low. The darker green safelights which are used for fast panchromatic materials are designed to transmit a light to which the eye is most sensitive and therefore it is blue-green light of wavelength $515\text{ m}\mu$ which these dark panchromatic screens transmit.

Later it will be necessary to discuss the methods adopted for the accurate specification of colours, but here we need only discuss briefly those properties of the eye which are the basis of colour vision. In the retina of the eye there are three types of receptors. These receptors are, we presume, cells which contain photochemical agents which produce electrical discharges to the nerve fibres when light of a certain quality falls upon them. We know that there must be receptors which are mainly sensitive to red, green, and blue light. Each of these receptors is, of course, sensitive to all of the colours of the spectrum, and as a result whatever quality light reaches the eye all three receptors are stimulated to a varying extent. The number of mixtures which can be obtained by varying the amount of these three sensations is obviously much larger than would be possible if the three sensitivity regions overlapped only slightly, for it is only where the overlap occurs that colour sensation can be produced. These colour receptors are present all over the retina of the eye and are the only ones in the central region, which is known as the fovea. Outside the central region, which is known as the extrafoveal or parafoveal area, the night-vision cells begin to appear and this is the reason why one has to look to one side of an object at night-time in order to be able to see it distinctly or even see it at all.

5. Ultra-Violet and Infra-Red Radiation. The human eye is sensitive only to a small part of the radiation which may fall on it. Radiation generally is produced when a body is energized, or heated. Any material, when heated, emits electromagnetic radiation, the quality and the quantity of which follow certain fundamental laws of physics which have been elaborated by Wien and Planck. One of the laws which has been derived is particularly interesting. This states that the product of the wavelength at which the energy is greatest and the temperature of the body in degrees Kelvin¹ is a constant value. It follows from this that as the tempera-

ture is raised so the energy distribution moves towards the shorter wavelengths, that is, towards the visible region. For all the radiators which we can make, such as tungsten lamps, the wavelength of maximum output is still in the infra-red, and so most of the radiation is not visible. In the case of tungsten lamps operating at a colour temperature of $3,000^\circ\text{K}$., over three-quarters of the energy is infra-red, which we feel as warmth, and only 10 per cent in the visible region. The

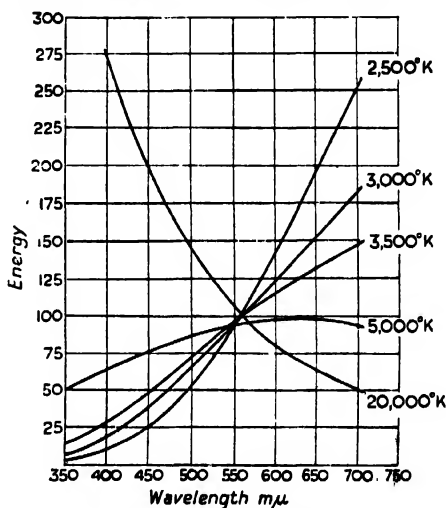


FIG. 1.3. SPECTRUM ENERGY CURVES OF BLACK-BODY RADIATORS OF DIFFERENT TEMPERATURES

amount in the ultra-violet is negligible. However, the light from the sun contains a considerable proportion of ultra-violet light. Fig. 1.3 shows the relative properties of the energy content of light sources of different colour temperatures.

The glasses generally employed in the construction of optical instruments transmit the ultra-violet down to about $350\text{ m}\mu$. The limit extends further to about $320\text{ m}\mu$ in the case of certain special glasses (Uviol). Thanks to the absorption of our atmosphere, the solar spectrum ends at about $300\text{ m}\mu$, which fact protects us from the very dangerous physiological effects of the shortest wavelength radiations. These can be produced by arcs between metal electrodes and transmitted by quartz (rock crystal) down to about $200\text{ m}\mu$, which is also approximately the limit of transparency of gelatine. By means of suitable apparatus (reflection gratings

¹ Degrees Kelvin = Degrees Centigrade + 273. The Kelvin scale starts at -273°C .

in vacuum), and by using sensitive emulsions without gelatine, it has been possible to study photographically the ultra-violet down to about $10\text{ m}\mu$, where it joins the X-rays.

Quartz lenses, used in conjunction with filters which transmit only ultra-violet, are employed in certain special applications of photography. A filter suitable for this purpose is a thin film of silver. In photographs obtained with these radiations alone, glass objects appear completely opaque; certain white flowers and pigments are indistinguishable from pure blacks, and, further, no background and no shadows appear in a landscape photographed in bright sunshine. The photograph looks as if it were taken in a dense fog (R. W. Wood, 1910).

The infra-red, which extends the visible spectrum beyond red, was of no photographic interest for a long time, its effects being chiefly thermal. Since the discovery of sensitizers (§ 218) for infra-red which are sufficiently easy to handle (E. Q. Adams and H. L. Haller, 1919; H. T. Clarke, 1925,) it has been possible to place on the market plates and films for infra-red photography up to 1 to 1.3μ . These sensitive emulsions must be kept and manipulated with special care. The extreme transparency of the atmosphere for infra-red has enabled photographs to be taken, with these rays only, of landscapes up to 330 miles distant from a high viewpoint. If all radiations of wavelengths below $700\text{ m}\mu$ are eliminated, green foliage is reproduced as white as snow, owing to the intense fluorescence of chlorophyll with a maximum near $740\text{ m}\mu$ (C. Dehre and A. Raffy, 1935), and as the blue of the sky is rendered as black and there is no shadow detail the landscape photographs thus taken in sunshine with a clear sky give an impression similar to that of a photograph taken by moonlight.

6. Colours in Nature. So far we have considered only light and the colour of light given out by incandescent bodies. But by far the largest part of our knowledge of the world about us results from our seeing of objects which are not self-luminous. With few exceptions we see things by the light which they reflect, although the light in the first instance is emitted by an incandescent source.

The manner in which the surfaces of any object reflect the incident light decides the appearance of that object. The surface may vary from highly polished to absolutely mat; when highly polished, the light is reflected directly, as in a mirror, with a mat surface the

incident light is diffused by the broken surface structure. The amount of the incident light which is reflected decides the surface brightness of the object. A light-toned surface reflects a large proportion of the light falling on it, a dark surface only a little, the remainder being absorbed. The absorption capacity of a surface depends not only on the nature of the surface, but in most cases varies with different wavelengths. Principally this is what decides the apparent colour of any object we see. The colour of non-luminous objects is the result of a subtraction process. A piece of red paper looks red because it absorbs the blue and green parts of the light falling on it, and reflects only the red. Similarly a green surface appears green because it absorbs blue and red.

However, the colours of the world around us are never monochromatic, for they always consist of reflections of broad bands of the spectrum. In general the brighter the surface appears the wider the spectral band it is reflecting. The yellow region of a spectrum is a very narrow band at the overlap of the red and green at wavelengths around $600\text{ m}\mu$. But if a yellow-coloured object were reflecting only this narrow band it would be very dark, since most of the incident light would be absorbed. Yellow pigments reflect all of the red and green regions too. Yellow is the result of stimulation of both red and green receptors in the eye.

The table given below shows the absorption and reflection characteristics of some common artists' colours.

Colours	Spectrum Regions Absorbed	Spectrum Regions Reflected
Ultramarine	Green and Red	Blue
Peacock Blue	Red	Blue and Green
Emerald Green	Red and Blue	Green
Cadmium Yellow	Blue	Red and Green
Vermilion	Blue and Green	Red
Carmine and Purples	Green	Red and Blue

The table shows the existence of colours which do not appear in the spectrum. Since the red and blue wavelengths appear at opposite ends there is no point at which the two overlap. Consequently mixtures of red and blue are never seen in a spectrum.

7. The Accurate Description of the Colours of Objects. For simplicity the colours in the table in the above section have been described by

division of the spectrum into three and indicating only reflection or no reflection (absorption). For scientific work (and this includes colour photography) a more precise method of describing the composition of a colour is needed. By measuring the amount of reflectance of a colour for *all* wavelengths throughout the spectrum a graph can be plotted which describes a colour more accurately. But the light which shines on the coloured surface must also be considered. To take an extreme case, a red light shining on a yellow surface, would be completely reflected and the surface would look red. The same surface in a green light would look green. In neither case could it appear yellow, since one of the two bands of wavelengths necessary to stimulate both red and green receptors of the eye and show yellow, was absent in each case. In normal circumstances, of course, the light would contain some quantity of all wavelengths, nevertheless the distribution of quantities must be considered.

The International Commission on Illumination in 1931 regularized the situation by setting up international standards of illuminants. These light sources are standardized to give certain quantities of light at all wavelengths throughout the spectrum, i.e. their light is of a specified spectrum energy distribution. The basic light-source is a tungsten lamp operating at 2,848°K. This is called S_A , for "artificial source." The spectral quality of this artificial light source is then modified by passing the light through coloured liquids of high stability. These give three other standard light sources. These are S_B (corresponding to British daylight) and S_O and S_D (American daylights). The liquid filters used are called Davis-Gibson filters after their designers Davis and Gibson of the National Bureau of Standards of America.

There is a third factor which must also be taken into account before we can accurately describe the composition of a colour. Since colour is a subjective phenomenon the sensitivity of the eye must be taken into account. This immediately raises the difficulty of the varying response of the human eye. A further part of the work of the International Commission on Illumination in 1931 was the specification of the so-called "standard observer." In the same way as the overall sensitivity curve of § 4 was drawn, three standard curves, representing the sensitivities of the three receptors was calculated. (Fig. 1.4).

Now that all necessary factors are known, they

have to be combined and the results shown in the convenient form of a graph.

The graph of the reflectance of the colour at each wavelength is taken and the values for each wavelength are multiplied by the amount of light emitted by the light source at that wavelength, from the spectral energy distribution curve. This value is then multiplied by the relative stimulation of the eye at that wavelength, from the I.C.I. curves. This last operation is carried out for all three receptors of the

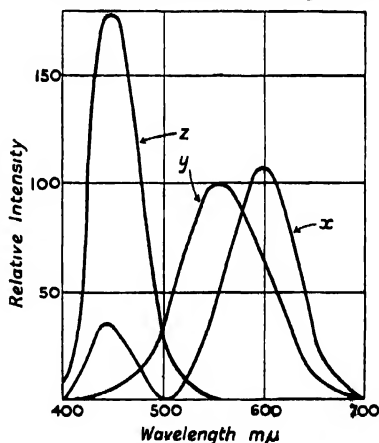


FIG. 1.4. THE RELATIVE STIMULATIONS OF THE THREE RECEPTORS OF THE STANDARD OBSERVER TO LIGHT OF DIFFERENT WAVELENGTHS (I.C.I. Standards)

eye, and as final results we obtain the relative stimulations of the receptors. We then characterize the integrated stimulations for each receptor by the letters X, Y, and Z for the red, green, and blue. If the sum of these stimulations is divided into the separate stimulations then we obtain values which always add up to one. These values are represented by x , y , and z . It is therefore only necessary to define two of these values as the third one is always the difference between unity and the sum of the first two. As we need to specify only two we can plot these two graphically. We may, for example, plot x , the red value, along the horizontal axis, with a maximum value of 1, and vertically y , the green value, which again can only have a maximum value of 1. If now all the colours of the spectrum are plotted each separately as if they were the only radiation falling on the eye, as in Fig. 1.5, then we should find that starting with the red end of the spectrum which would give us nearly

the maximum value of x on the x scale, we should move towards the top end of the y scale as we move towards the green. As we move from the green to the blue so the position of the points on the graph would move towards zero on both scales because neither the green nor red receptors would be very much stimulated by the blue light. We should come to a point where of course the light is no longer visible and no further points can be plotted. By drawing a straight line between the two ends of the curve,

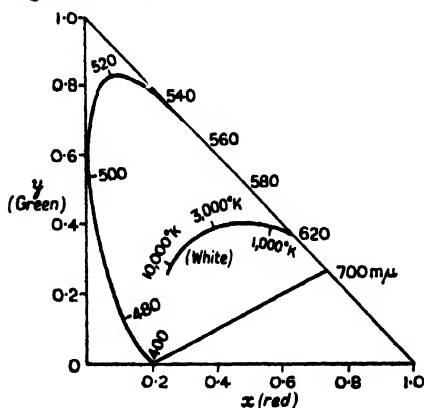


FIG. 1.5. THE I.C.I. COLOUR TRIANGLE SHOWING THE LOCI OF BLACK-BODY RADIATIONS OF DIFFERENT COLOUR TEMPERATURES AND THE SPECTRUM LOCUS

the blue end and the red end, we shall obtain a rough triangle. All the colours are formed by mixtures of the spectrum colours and therefore all colours lie inside this triangle. White light which is a fairly uniform mixture of all the spectrum colours lies in the centre. Any colour can now be plotted on this diagram, and the position on the diagram specifies the colour precisely, except for its brightness.

As the position of the colours or, as they are called, the chromaticity values, move from the white point towards the boundary of the colour region, the proportion of spectrum colour in the mixture increases. We then say that the saturation or purity has increased. This supposes that any colour can be matched by a mixture of white light and a spectrum colour, and so far as the appearance is concerned this is correct. Furthermore, it means that more than one make-up for a colour can be represented by a single point on the colour triangle, because it is only the overall effect of the spectral

reflectance curve that is represented by the chromaticity value and not the particular spectral reflectance curve. The spectrum colour which together with white can be used to define the colour under consideration has a determinable wavelength which is known as the dominant wavelength. It follows from the rules and definitions of colorimetry that to obtain the dominant wavelength it is only necessary to draw a straight line through the white point and the colour and to note at what wavelength it intersects the locus of the spectrum colours.

As well as pigmentary colours, the colours of incandescent materials can also be plotted on the diagram. The chromaticities of black-body radiators if plotted in the colour triangle form a smooth curve which extends from the red colours through the white to the blue colours. The common sources of illumination for colorimetry can be located on or near this black-body locus. S_A (a tungsten lamp at 2,848°K) falls on the locus, and the other colours which are defined by the effect of liquid colour filters on the above source fall at points which are slightly off the locus and situated further towards the blue end.

8. Colours by Transmitted Light. In addition to the modification of white light by pigments, we can also observe that transparent media can effect a change. This is a much more easily visualized process, for if we shine a beam of white light through a piece of red glass, for example, we can see that all other parts of the spectrum have been subtracted from the beam which emerges from the other side. The light is not diffused in its passage through such a material, but parts of the spectrum have been absorbed by the dye which it contains. Dyes can be made which will absorb light in almost any part of the spectrum. The dye chemicals have a certain molecular structure in which electrons are assumed to resonate. Each structure has its natural frequency at which it will absorb a great deal of energy. This leads to an absorption band in the spectrum. By incorporating several dyes it is possible to eliminate parts of the spectrum until selected portions only are transmitted. Such selective absorbers or filters are of great practical importance in photography and are usually made by incorporating dyes in a warm gelatine solution and casting it into thin sheets. Alternatively, the dyes can be incorporated into glass during manufacture, but only a restricted range of colours can be obtained by this method since

LIGHT AND COLOUR

the temperature at which the colouring matter must be incorporated imposes a great many restrictions.

A given light-filter absorbs a constant proportion of the wavelengths which fall on it,

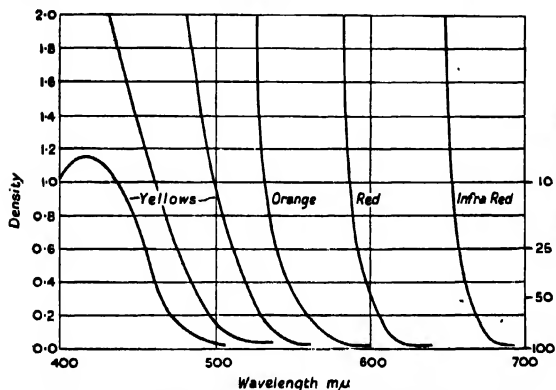


FIG. 1.6. TRANSMISSION CURVES OF A SERIES OF FILTERS

irrespective of the intensity. The characteristics of a filter are generally shown graphically. The absorption is plotted on the vertical axis on a logarithmic scale, against wavelength on the horizontal scale. Fig. 1.6 shows such a graph. Instead of absorption, the transmission of the filter is sometimes shown, but there is no essential difference between the two methods since the absorption density is related to the transmission by the formula $D = 2 - \log_{10} T$, where D is density and T is transmission as a percentage (§ 15). A density of 0.0 corresponds to a transmission of 100 per cent, a density of 1.0 to a transmission of 10 per cent and so on. If two filters of different colours are together placed in the path of a beam of white light, their combined transmissions are the product of their individual transmissions at each wavelength. On the logarithmic scale of absorption density this means that their respective absorptions are added. This is shown graphically in Fig. 1.7. In Fig. 1.8 the same curves are shown plotted as transmission percentages.

In practice it is of no importance where in the light-path the filters are placed since a filter is constant in its absorption characteristics. There would be no difference in effect between a filter

placed over a light-source and the same filter placed over the camera lens.

9. Practical Light Sources. One of the most important considerations in photography is the source of light, for the performance of the material and the tone-rendering of the subject depend enormously on the choice of illuminant. The illuminants can be divided into natural and artificial. Daylight which comes from the sun is reasonably constant in its colour quality. There are a number of factors which influence the final conditions and which apparently make daylight variable. Direct daylight or, more precisely, sunlight, is the constant factor and on this is superimposed light which may be scattered by clouds or mist and also blue light which is scattered from the outer atmosphere of the earth. The amount of blue light which is scattered varies with the direction from which it is coming

and therefore the resultant effect depends on which part of the sky is most effective in illuminating the subject. In the shadows formed

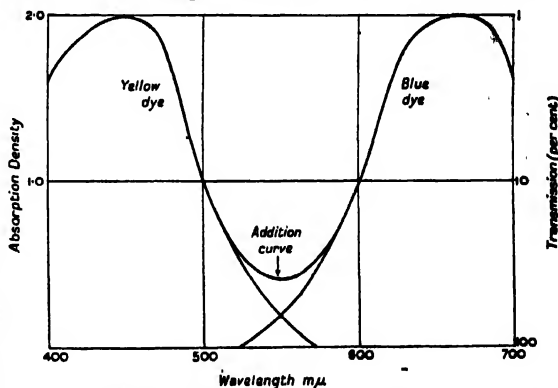


FIG. 1.7. ABSORPTION CURVES OF TWO FILTERS, SHOWING THE ADDITIVITY OF THEIR ABSORPTIONS WHEN THE TWO FILTERS ARE USED TOGETHER

by the sun the light is very blue and has a decided effect on the colour rendering of colour film. Where exact colour reproduction is aimed at, as in colour photographic processes, and when it is necessary to take the photographs out-of-doors, it is essential that the aspect of the lighting be considered carefully.

There is probably far more scope in the field

of artificial illuminants; recent developments in this field have not yet been fully explored by photographers. The sources which are termed artificial can be very broadly divided into two, incandescent lamps and discharge arcs.

The incandescent sources are those which are

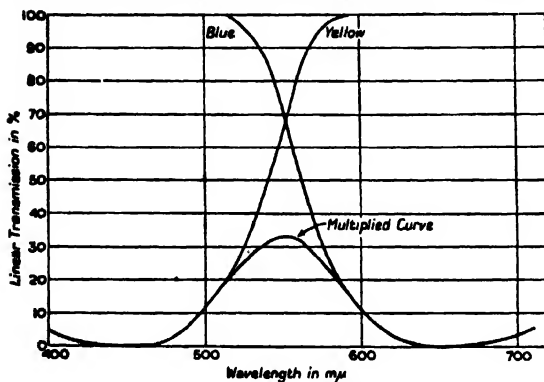


FIG. 1.8. TRANSMISSION CURVES OF TWO FILTERS WHEN USED TOGETHER

heated to a high temperature in order to produce their radiation. As the temperature is increased so the amount of light emitted and thus the efficiency increases for photographic purposes. The temperature can be raised until the substance is almost melting in order that the efficiency shall be a maximum. Unfortunately, however, all substances have vapour pressures which increase with the temperature. This implies an increasing rate of evaporation and means that if the source is in the form of a filament it becomes increasingly fragile and finally susceptible to shock or unusual rise in temperature, which causes it to melt or break. That is briefly what happens to (tungsten) metal-filament lamps. The higher the temperature at which the lamp is worked (by the use of higher voltages) the higher the photographic efficiency and the shorter the life.

A widely used type of source is the carbon arc, which is part discharge and part incandescent. Carbon is a conducting material and if two carbon electrodes touching one another are placed in series with a resistance and a current passed through them then an arc is formed when the carbons are separated. The current is carried by a stream of electrons and ions which bombard the carbons which slowly burn away, mostly from the cathode. The cathode at a higher voltage attracts the carbon ions, which reach

it to give up their energy in the form of heat. The cathode becomes very hot and will then radiate light. This is the form of the high intensity carbon arc which is of extremely high efficiency because of its very high colour temperature. The high temperature means that the energy distribution is such that the source is predominantly blue and lacking red. In order to compensate for the lack of red light salts of various metals such as strontium, calcium, and sodium are introduced into the core of the carbon rod; the lamp is then described as a flame arc. The metals burn in the flame of the arc and emit their characteristic spectral light. Carbon arcs are usually operated on direct current supplies in series with a resistance which consumes more than half of the electrical energy. Even so this type of lamp is still much more efficient for producing light than any other. The great advantage in operation is that they can be struck instantly and with an automatic feed will run for hours until the

carbons are burnt away. Arc-lamps are used in the film industry for studio work and also for projection.

The remaining sources of light are the discharge arcs and fluorescent lamps, and for these

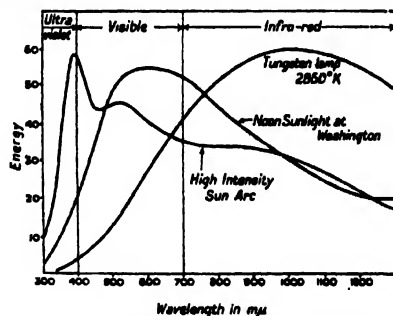


FIG. 1.9. SPECTRUM ENERGY DISTRIBUTION CURVES OF VARIOUS LIGHT SOURCES, ALL OF WHICH, ON THEIR OWN, APPEAR TO PRODUCE WHITE LIGHT

the metal mercury plays a prominent part. If a globe of mercury is sealed in a partly exhausted vessel it is possible to start an arc between two electrodes inside the vessel. The discharge produces heat which in turn vaporizes more mercury and provides a greater discharge of energy. This continues until the optimum

conditions of temperature and efficiency are obtained. Unlike the incandescent sources the mercury atoms are disturbed in a definite manner which depends on the atomic structure (see § 3). The light from discharge sources is thus in the form of spectrum lines or emission spectra.

Mercury has two yellow lines very close together at $578\text{ m}\mu$, a green line at $546\text{ m}\mu$, a blue line at $435\text{ m}\mu$, and a violet line at $405\text{ m}\mu$. It has no infra-red, but numerous ultra-violet lines, the two best known being at $365\text{ m}\mu$ in the near ultra-violet and the resonance line at $254\text{ m}\mu$, which accounts for a considerable proportion of the energy radiated. As temperature and pressure are increased, the efficiency increases and more of the light is radiated in the visible than in the ultra-violet wavelengths. The latest design of lamps utilizes cadmium metal, which besides spectral lines in the blue and blue-green has a very strong line in the red, thus compensating for the lack of red in the mercury arc. These mercury-cadmium lamps have been produced for very high wattages and efficiencies which make them comparable with the best carbon arcs. Furthermore, the sources have been made very compact so that they can be incorporated into spotlights and projectors.

If the inside of a tube in which there is a mercury arc is coated with a fluorescent powder, the ultra-violet radiation is absorbed by the powder which then re-emits the radiation as visible light. The efficiency of this process is very high if a low pressure arc is used in which the majority of energy is radiated in the ultra-violet. Usually three powders are used in the fluorescent tubes, to produce either cold daylight or warm white light, which are comparable to true daylight and artificial light respectively. These lamps are very often used to supplement daylight in places like art galleries, for photographic reproduction purposes, or for illuminating transparencies. X-ray illuminators and colour-film viewers also use fluorescent lamps, as they are more economical than tungsten lamps.

In any consideration on spectral sensitivity as, for example, of a photographic emulsion (see § 216) or of the eye (see § 4), use is made of the "equal energy spectrum." This is the spectrum of an imaginary light source which emits equal amounts of energy into any one band of wavelengths. Spectral sensitivity curves, as referred to an equal energy spectrum, are easily prepared if the spectral emission curve of the source of light used is known.

CHAPTER II

QUANTITY OF LIGHT : PHOTOMETRIC UNITS

10. Intensity and Brightness. The luminous power of a source of light is measured in *candles*.¹ This figure is determined by comparing the lamp to the standard candle, an internationally agreed light-source which gives out a fixed amount of light when burning at a specified rate, under standard conditions.

The standard candle was first agreed upon as an international unit in 1909, when the light-sources available worked at rather lower colour temperatures than they do to-day. In 1937, a new system of units was agreed upon, which takes as standard the brightness of a black body raised to the temperature of freezing platinum (2,041·3°K). This source has a brightness of 60 candles per square centimetre. The connexion between the old standard candle and the new is simple: 1 new standard candle = 0·98 old standard candles. The new standard was to have come into use on 1st January, 1940, but this has been deferred until further comparisons have been made.

In the new standard a further factor is introduced, that of the area of the light source. The *intensity* of a source is expressed in *candles*, the *brightness*, in candles per unit area—in this case *candles per square centimetre*.

11. Illumination. If the light source were a point, without supports, then the radiation would be the same in all directions. In fact, owing to the mechanics of electric lamp construction the output is never uniform in all directions. In some cases special efforts are made by the manufacturers to direct the light in the direction in which it will be most useful, for example, in the case of projector-lamps, where all the light which does not fall on the condenser is wasted. For a point source the amount of light which falls on a surface depends on the distance of the lamp from the surface. The intensity of illumination of the surface will vary according to the *Inverse Square Law*, that is, the illumination is inversely proportional to the square of the distance. Where the measure of distance is the foot, the measure of illumination of a surface is the foot-candle, that is the amount of light the surface will receive from a source of one candlepower at a distance of one

foot. If the one-candlepower source is moved to a distance of two feet, the illumination will fall in accordance with the inverse square law ($\frac{C}{D^2}$,

where C is the power of the source and D the distance) to $\frac{1}{4}$ foot-candles. This calculation is only strictly true for a point source. However, in practice the law can be applied with sufficient accuracy in all cases where the dimensions of the source are only a small fraction of the distance from the source to the illuminated surface.

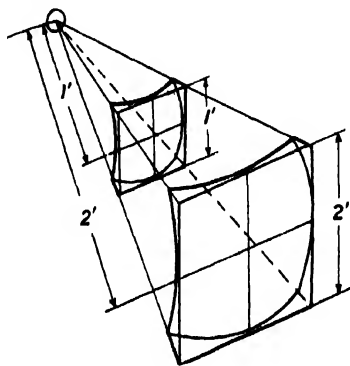


FIG 2.1. THE FALLING OFF IN ILLUMINATION FROM A POINT SOURCE IN ACCORDANCE WITH THE INVERSE SQUARE LAW

The above calculations have been based on the assumption that the surface receiving light from the source is at right angles to the line joining the two. When this is not true the angle by which the surface deviates from the normal must be taken into account. If the angle (measured from the normal) is α then the intensity of illumination will be $\frac{C}{D^2} \cos \alpha$.

When the light source is not small enough to be considered a point, then the inverse square law no longer applies. The most striking example we can consider, is the illumination from a fluorescent tube. A few inches away from the lamp the illumination is constant over quite a variation of distance. At a distance of a foot or two the illumination is proportional to $\frac{C}{D}$, and from a few feet onwards the illumination obeys

¹ The internationally adopted designation of this is the *candela*.

the $\frac{1}{D^2}$ law, because at that distance the size of the lamp and the angle which it subtends are becoming relatively unimportant.

Whenever there is any form of optical system such as mirrors or lenses, which are directing the flux from the lamp, then again the inverse square law does not apply. For instance, the output of projectors is quoted as a *flux*, and the output of searchlights as *beam intensity*.

For practical photographic purposes the difference between a light source of small size and a large area source is seen in the quality of the lighting. A small source of high brightness will form sharp shadows and small reflections of high brightness, i.e. highlights. For equal intensity a low-brightness source of large surface area gives a more diffused light and produces less sharply defined shadows.

When the measure of distance is the metre the illumination is measured in metre-candles or lux. The metre-candle is a smaller unit than the foot-candle since the illumination of a surface at one metre will be less than that on the same surface moved in to a distance of one foot. Since illumination varies inversely as the square of the distance and one metre is equal to 3.281 feet there are $10.765 (3.281^2)$ metre-candles to 1 foot-candle.

When a larger metric unit is needed, the *centimetre-candle* or *phot* is the unit. One foot-candle is equal to 1.0765 *milli-phot*.

12. Total Light Output of a Lamp. To measure the total amount of light given out by a light source we must consider the radiation all round the source. If we imagine a sphere totally enclosing a source of one candlepower, the total area of the inside surface of the sphere will be $4\pi r^2$, where π is the constant 3.14 and r is the radius of the sphere. Whatever unit is used to measure the distance from the source to the surface of the sphere (r), the surface area will always be 12.56 (4×3.14) units. The total light flux from a source of one candlepower is therefore (assuming a theoretical source, without supports) 12.56 *lumens*, in either the metric system or the foot-candle system. Since the light is not always being radiated continuously the time of radiation must also be considered to calculate the total light output. The total quantity of light given out by a source of one candlepower in one second is 12.56 lumen-seconds.

This method of specifying the light output of a lamp is commonly used for flashbulbs, where

the life of the lamp is short, but the intensity of the source in that short time is very high. A Speed Midget Bulb has a total light output of 5,000 lumen-seconds with a peak output of 0.7 million lumens.

13. The Brightness of Reflecting Surfaces. So far we have considered only the quantity of light given out by a light source. When the light falls on a surface it is in part reflected and the surface becomes in some degree a source of light itself, and it can be assigned a brightness. The amount of light reflected depends on the actual surface of the material, which may vary from glossy to mat, and the underlying tone which may vary from white to black.

A highly glossy surface will reflect principally in one direction, in a manner similar to a mirror, and obeying the same laws. Reflections of this sort are sometimes called specular reflections. A completely mat surface will give diffuse reflection, in which the light is scattered and reflected at all angles. In practice, of course, the types of surface vary between these two extremes, and to gain an accurate picture of the reflectance of a particular surface the reflected light must be measured at all angles and a polar reflection curve plotted.

The majority of objects which we see by reflected light, are the result of diffuse reflection, although specular reflections are sometimes seen and indeed are of some importance since they provide highlights which give the eye a clue to the modelling and surface texture.

The brightness of a completely diffusing surface is measured by taking the intensity for a given direction and dividing by the area of the surface as seen from this direction. The unit of brightness is then the *candle per unit area*. In general use this is the square foot, or the square metre. The brightness can be specified in another way. One *lambert* is the brightness of a perfectly diffusing surface reflecting one lumen per square centimetre. One *foot-lambert* is the brightness of a perfectly diffusing surface reflecting one lumen per square foot. A completely reflecting surface under an illumination of one foot-candle therefore has a brightness of one foot-lambert.

14. Reflection Factor. Any reflecting surface can be assigned a *reflection factor*, which is the ratio of the flux reflected by the surface to the flux incident upon it. This will of course depend on the surface, whether it is glossy or mat and the tone, but it will also depend on the angle of the incident light and the angle at which the

reflected light is collected for measurement. This factor becomes especially noticeable as the surface approaches the perfect specular reflector.

It is common practice to illuminate a surface in a direction perpendicular to the surface (i.e. normally). The reflected light is then measured at an angle of 45° . For special needs these two angles may be varied. The following are a few values of extremes of reflectance values—

Black velvet	0.004
Chinese Black on Paper	0.01
Photographic Paper, Black Glossy	0.02
Photographic Paper, Black Mat	0.06
Black Printing Ink on Paper	0.10
White Paper ordinary	0.60
White Paper baryta-coated	0.80
Magnesium Oxide deposit	0.90

For a truly diffusing surface the brightness of a surface in candles per square foot is equal to the product of the illumination in foot-candles and the reflection factor divided by π (3.14).

15. **Transmission, Opacity and Density.** When light passes through any transparent or translucent medium a proportion of the incident light is absorbed and lost, and the remainder emerges. We are dependent on this fact for the production of prints from negatives, for photographic negatives consist of varying quantities of black silver suspended in transparent gelatine. The amount of light which a negative transmits at any one point depends on the quantity of silver at that point. The light transmission of any such semi-transparent material is the ratio between the incident light and the emergent light.

Transmission percentage

$$= \frac{\text{Emergent light}}{\text{Incident light}} \times 100$$

• In addition to the light lost by absorption, the silver of a negative also diffuses the light. This, if not taken into account, would make the figure for emergent light incorrect, since all of it could not be collected. In practice the transparency of a negative is measured by placing the negative in contact with an evenly illuminated

opal glass diffuser. This ensures that the value obtained does not differ seriously from the effective value (§ 201).

It is more common to indicate the transmission of negatives or positives by their density. This is derived from the reciprocal of the transmission (the opacity). Density units are much more practical, since they are logarithmic units, in fact the logarithm to the base 10 of the reciprocal of the transmission. The following table gives a few values of density with their approximate corresponding values of opacity and transmission.

Density	Opacity	Transmission (percentage)
0.00	1.00	100
0.05	1.10	89
0.1	1.26	79
0.2	1.6	63
0.3	2	50
0.6	4	25
0.9	8	12.5
1.0	10	10
1.3	20	5
1.6	40	2.5
1.9	80	1.25
2.0	100	1.00

When two pieces of partly transmitting material are placed together the resulting density is the sum of the individual densities. This principle of additivity of density is particularly important in the case of filters (§ 8), and in the correction of separation negatives by masking (§ 1005).

16. **Reflection Density.** In the case of images on an opaque support it is necessary to measure the reflection density. This is the logarithm of the reciprocal of the reflection factor (§ 14). But it must be noted that for papers with peculiar surface structures, grained or embossed, the reflection values depend to a certain extent on the orientation of the paper with respect to the direction of the incident light.

CHAPTER III

LIMITS OF BRIGHTNESS IN PHOTOGRAPHIC SUBJECTS

17. **Range between Extreme Brightnesses in some Common Cases.** The extent of the brightness range of everyday objects is not generally known and as a result there is a tendency to assume that the ranges are very large, whereas in fact the majority of these are moderate although not necessarily within the tone-range of the photographic material. Measurements which have been carried out, either indirectly by means of photographic plates (Hurter and Driffield, 1890) or by direct (visual) photometric tests of points in a subject (Mees, 1914; Goldberg, 1919, 1941; L. A. Jones, 1938), have allowed us to assign numerical values to the brightnesses of various parts of photographic subjects, such as a landscape, an interior scene, a portrait, etc.

In a sunlit landscape, without any dense shadows in the foreground, the brightness of the sky (comparable to that of a white paper receiving an illumination of about 1,600 foot-candles (§ 11)) is not more than about 25 to 30 times that of the deepest shadows. The ratio of the extreme brightnesses for certain subjects is indicated roughly in the following table—

Subject	Ratio of extreme brightnesses
Landscape, with sun in the field of view	2,000,000 : 1
Interior, with windows showing a sunlit landscape	1,000 : 1
Portrait, artificial light, white clothes	100 : 1
Landscape with white sunlit areas and dense shadows in foreground	60 : 1
Lampblack on white paper	20 : 1
Landscape in diffused light, with dark foreground	15 : 1
Interior, no windows or reflections in field of view	10 : 1
The earth, viewed from above: balloon, aeroplane (vertical view)	4 : 1
Landscape in misty weather	2 : 1

The relatively low values of these ratios are due to two facts: firstly, that absolute blacks do not exist in Nature, and, secondly, that, with the exception of polished objects, even the whitest ones reflect only a part of the light which they receive. The only way to get an

absolute black is through a relatively small hole in a large box, the interior of which is entirely covered with black velvet, or, failing this, a coating of lamp black and dextrin (§ 253).

The most highly reflecting material is magnesium oxide which is deposited on a polished silver plate by burning magnesium; it has a reflection factor of about 98 per cent. Good white papers have reflection factors of about 90 per cent and whitewashed ceilings of about 80 per cent. The lowest reflection factors are those with peculiar surface structure which tend to trap the light, such as brushed velvet and black paper having a fibrous pile. These may have reflections of less than 1 per cent. Photographic blacks on paper, even on glossy paper, are never less than 2 per cent and are as much as 4 or 5 per cent on mat papers. The tone range of landscapes is considerably reduced by removing the shadows. This is effected by an overcast sky. In this condition the reflection factors still hold but reflection factors in landscapes are limited to a very small range. The resultant picture is not usually attractive and is only relieved when the sun comes out again and casts its shadows to brighten up the scene by increasing the tone-range.

In a landscape, the ratio of the extreme brightnesses is less for objects farther away. If the distant parts of a landscape are examined with a telescope (or even with a cardboard tube, so as to isolate part of the field of view), no heavy shadow can be observed; diffused light from the atmosphere due to dust and water-droplets in suspension is superposed on the direct light from the object observed. At the farthest distance which can be seen in the direction of the horizon, no detail can be observed, all objects having the same brightness as the sky, and becoming indistinguishable in a kind of bluish mist, called the *atmospheric haze*. Painters and draughtsmen make use of this fact (known to them as *aerial perspective*) when they wish to convey the impression of extreme distance.

18. **Sensitivity of the Eye.** The eye is really part of the brain. Over a very wide range of lighting conditions both eye and brain operate

quite happily. There is a range of tone values which the eye can appreciate in its field of view. This range is reasonably constant over quite a wide range of average brightnesses. That is to say the tone range of the eye is the same on a sunny day as on a dark winter's day. This ability is known as the adaptation power of the eye. Over and above this effect, the mechanism of which is not known precisely, there is the automatic regulation introduced by the reflex action of the pupil of the eye. Under daylight conditions the pupil tends to operate at a diameter of about 2 mm, but if the brightness is altered quickly there is a reflex action which tends to compensate for the change of image brightness. If the brightness is reduced then within 5-10 seconds the pupil opens up to almost 8 mm, giving a substantial increase in the brightness of the image. This action is a protective mechanism; afterwards the pupil slowly contracts back to 2 mm. At low levels of illumination the pupil always remains fully dilated.

Under normal conditions of lighting the contrast sensitivity of the eye is about 1 per cent. This means that two patches of light separated by a very sharp dividing line, will be just noticeably different if their brightnesses differ by one per cent. A considerably larger difference is necessary if the two patches are separated or if the patches are in any way slightly non-uniform.

The contrast sensitivity decreases as daylight diminishes, and under weak artificial lighting the minimum brightness difference rises to 5 and 10 per cent and even more at lower levels. The daylight mechanism of the eye operates smoothly from 1,000 foot-candles (bright sun) to 10 foot-candles (dull winter day). Moonlight ranging from 1/50 foot-candle for a full moon to 1/1,000 foot-candle for a new moon stimulates both day and night vision, but the loss of colour vision is quite noticeable. Shadow detail is completely obscured. At 1/1,000 foot-candles day vision does not operate, but by this time night vision has come fully into operation and operates through the starlight region down to 1/1,000,000 foot-candle.

ILLUMINATIONS IN FOOT-CANDLES

Open air, fine weather	Interiors, day time	Interiors, night time, artificial lighting	Streets at night time, artificial lighting
500	50	5	0.5

19. Perception of Details of Brightness. When the eye is adapted to any particular level of illumination the supply of photochemicals to the retina of the eye reaches an equilibrium. This is known as adaptation and takes place quite quickly. The next question is over what range of brightnesses can the eye operate and still obtain this state of adaptation. Over a range of 10 to 1 in brightness in both directions the eye has much the same acuity and contrast sensitivity. Above and below this range the eye finds it increasingly difficult to operate; at the high levels because the photochemical is rapidly bleached out; and at the lower end merely because there is insufficient light. It can be seen from this that the best conditions are those in which the object to be viewed is at the same level of brightness as that to which the eye is adapted. Therefore to see well it is not necessary to have plenty of light but it is necessary that the light should be in the right balance. Discrimination of subtleties of brightness, i.e. contrast sensitivity, is constant over a range of 1 to 1,000 foot-lamberts, which can be obtained by bright artificial light and sunlight. If, however, the object to be viewed is dark then it is necessary to increase the level of illumination in order to compensate for the low reflection factor. For instance if black cloth is being stitched on a sewing-machine and the work necessitates some precision it is necessary for the level of illumination to be some 30 times as much as one would need for white cloth. R. J. Lythgoe (1932), has laid down the basis of the practical aspects of lighting and visual acuity.

So far the contrast sensitivity has been considered to remain constant over a wide range of brightnesses but the sensitivity of discrimination also depends on the way in which the brightnesses are presented to the observer. In optical instruments it is usual to present them as two adjacent patches having an extremely sharp dividing line, so sharp that when the patches are equal in brightness they appear as a single patch without trace of the separation line. As the sharpness of the line is reduced the sensitivity gradually decreases to several per cent. As the patches are separated the sensitivity drops to a very low value, depending on the surrounding brightness. If the patches are not uniform in brightness, but, for example, of grainy appearance, the sensitivity is lessened. A more practical application to photography is that in which the brightness varies gradually

over an area. It is not possible to lay down definite rules as to what is visible and what is not, but it is safe to say that differences as great as 50 per cent in brightness are not noticeable if the variation is smooth. For this reason the fall-off in illumination across the image plane of cameras, enlarger, and projectors is tolerable.

Small differences of brightness can sometimes be confused with small differences in colour. This becomes very noticeable when judgments are being passed on the accuracy of matching of colours in colour processes: in fact by an

association of ideas it is usual to tie up difference of colour with difference of brightness.

In black-and-white photography it is sometimes difficult to know beforehand how a scene will be rendered in the various tones of the grey scale. It helps to view the scene through a monochromatic yellow filter which apparently reduces the whole of the scene to a very restricted range of yellows and browns of different brightnesses. The only disadvantage or inaccuracy in this method is that the blues and reds tend to be rendered lower in brightness than they actually are.

CHAPTER IV

PHOTOGRAPHIC PICTURES: THE AESTHETIC PICTURE; THE IDEAL SCIENTIFIC PICTURE

20. Negative and Positive. The image obtained by the usual photographic processes is a *negative* (Fig. 4.1), in which the lights in the subject are reproduced as opaque and the shadows as transparent areas. If this negative is placed in contact with another photographic emulsion, and an exposure is made through it, we can produce another image which is the reverse of the negative and therefore like the original subject (Fig. 4.2).

If the positive is on a transparent support it is usually called a positive transparency, but if it is on an opaque base, such as paper, it is called a print.

21. Range of Extreme Brightnesses in a Positive. The following table indicates the ratio of the extreme brightnesses in images on paper, obtained by different processes and viewed under normal conditions.

Typographical impression	from 10 : 1 to 35 : 1
Black tone photographs, mat surface	from 15 : 1 to 20 : 1
Intaglio print (photogravure)	less than 35 : 1
Carbon prints, black tone	about 40 : 1
Black tone photographs, best quality glossy surface	50 : 1

These values should be considered as the maxima, corresponding with materials of the best quality and with perfect technique. They vary with the conditions under which prints are viewed; an image in which the whites are more glossy than the blacks appears more contrasty when it is viewed in the open air by diffused light than in the light from a source which is almost a point. It appears still more contrasty when it is illuminated under good conditions near a window (Nutting, 1914).

22. The Ideal Scientific Reproduction. In a photograph which reproduces a subject with absolute fidelity, there ought to be equality between each of the luminosities of the picture and the luminosity of the subject at the corresponding point. Obviously this equality is only possible for a certain value of the illumination of the picture and for all other values reduces to a proportionality.

Even supposing that the photographic processes were able to reproduce the subject faithfully over the limited range of luminosities which can be obtained with different papers, it

can be seen that reproduction under exact conditions is impossible with an image viewed by reflection, since the range of extreme luminosities of the subject would be limited to 20 : 1 in the case of mat prints, or 50 : 1 in the case of glossy prints. There is no such narrow limit to this interval in the case of images viewed as transparencies (diapositives). Note that this advantage is to a great extent lost if such an image is examined by reflection from its projection on to an opaque screen, instead of being examined directly. It may be stated as a general rule that for normal subjects, the image on paper should, in order to give natural sensations, differentiate, in the different regions, brightnesses of which the ratios should be respectively—

Highlights, 5 per cent; halflights, 10 per cent; deep shadows, 25 per cent.

For purely record purposes, papers with glossy surfaces are superior, since they not only allow details to be read under considerable magnification (which cannot be done with a print the surface of which has a more or less coarse structure), but also permit of a more correct representation of an extended range of brightnesses.

Nevertheless, one is often led deliberately to depart from the ideal proportionality between the brightnesses of the image and those of the subject, and to "compress" the scale of brightnesses of the image in such a way as to bring it between the limits which are available in practice.

23. The Aesthetic Picture. It would obviously be correct to reproduce strictly the various tones which occur in a dark cave if the photograph obtained was going to be used to ornament the walls of this cave, or of any other place of the same illumination. Since, however, photographs are usually intended to be looked at in a well-lit room, they ought therefore to render the physiological relations of the different luminosities of the object, and not their physical values.

The apparent relative brightnesses of any scene or object change to a more or less marked degree when the intensity of the illumination in which it is examined is modified, just as if the intensity scale were transposed into a new key (F. F. Renwick, 1918).

A lump of coal illuminated by direct sunshine can send back more light than a lump of chalk



FIG. 4.1. THE NEGATIVE IMAGE



FIG. 4.2 THE POSITIVE IMAGE

in the shade, and yet we see the coal as black and the chalk as white. This physiological interpretation does not occur when we look at a photograph in which we may take the image of a black object for that of a white one, or conversely, according to their relative brightnesses (H. Arens, 1932).

A finished photograph should give an impression of the original scene, but to say that the camera cannot lie is possibly the most misleading statement ever made.

Photographic tone reproduction can be divided into two parts: the objective part, which merely depends upon the brightness and tone-range of the original and of the reproduction, and the subjective part which depends upon the observer's sensory mechanisms.

24. The Objective Phase. Experiments were carried out by L. A. Jones (1921), in which he laid down a photographic technique which enables true reproduction to be achieved within the limitation of the process. Starting off with a typical emulsion a number of negatives with varying exposure were prepared and from these paper prints were made at different contrasts and exposures. These prints were assessed by large numbers of observers and the statistical results analysed to indicate the most acceptable results. Jones's work on this subject indicated the acceptability of average prints.

25. The Subjective Phase. There are other considerations in the presentation of a print in addition to the fidelity of a reproduction of brightness. R. G. Hopkinson (1937), attempting to reproduce exactly the result of a street-lighting installation on a paper print, has developed a technique which fulfils the subjective part of presentation. This work aimed at setting the observer's mind, through his visual mechanism, to a state in which his subjective mechanism is working under the same conditions as when the original was viewed. High-key and low-key effects are well known as a means of suggesting to the observer that the lighting arrangements are very bright or very dark. Hopkinson went still further with this idea and produced prints and viewing conditions which interpreted the original lighting conditions to such an extent that it was possible to judge the results of street-lighting installations on a photographic set-up and thus avoid the necessity for a visit to the scene with all the difficulties of judging whether any improvement had been effected by lighting changes.

Work of great importance in this field is that

by R. M. Evans and Miss J. Klute (1944). They considered more closely the subjective side of tone reproduction and attempted to show the various stages that a professional or studio photographer goes through when making his lighting arrangements, which he finds necessary by experience, to produce a pleasing impression of the original. The basis of Evans's work is the psychological indifference to variations of brightness, which are due to different intensities of illumination. For instance, normally nobody is in the least worried to see a person's face in shadow or that light sources throw shadows of noses in two directions. The reason for this acceptance is that the subject is live and moving and that one's attention is not centred on these aspects but on other things. At any rate it is obvious that the shadows are shadows and that the skin is uniform in tone. The photographic reproduction, however, both projects the solid object on to a plane, and freezes the live subject in movement, and with black-and-white photography one must decide what was colour and what was brightness. And so it is necessary to distort deliberately the exact physical tone reproduction in order to convey the impression required. To do this it is necessary to restrict severely the brightness range of the subject. The densities on the print must indicate not only the reflection characteristics of the original, that is, whether it is a white or a grey or a black surface, but also whether it is dimly or brightly lit. The final lighting arrangement differs considerably from the conditions one would choose for direct inspection and is usually very near almost perfectly uniform illumination. From this it follows that all unrelated background must be independently lit to a level comparable to that of the main objects in the picture. Shadow portions must be increased in brightness. The gradation of shadows must be decreased, often by the use of auxiliary lighting. Finally, the brightness of the print must be adjusted (by exposure, and perhaps development), so that the main object seems to indicate the true reflection factor; it must be the true reflection factor if the surround of the picture is white and if there are in the print no large areas of black or white to form a contrast.

If, however, there is the need or the wish to suggest extraordinary lighting conditions, then it is necessary to over- or under-expose the whole of the print and also to arrange the mount to be of suitable reflectivity in order to suggest the necessary high- or low-key effect.

CHAPTER V

PERSPECTIVE : MONOCULAR AND BINOCULAR VISION

26. Geometrical Perspective. Although the word *perspective* (from the Latin: to see through) is often used loosely, it is capable of strict definition. If straight lines are drawn from all the points of an object or group of objects to a fixed point (the *viewpoint* or *centre of projection*) and if those lines pass through a certain surface (the *surface of projection*), the image traced out on that surface is the perspective of the object or group of objects. This surface is generally a vertical plane, but is sometimes a cylindrical surface (panoramas), or a segment of a sphere (cupolas), or, more rarely, some other surface.

Practically, according to Leonardo da Vinci, the perspective may be defined as the trace which would be obtained on a transparent surface (glass, or gauze stretched on a frame in the case of a plane perspective), when one eye is kept in a fixed position determined by a sighthole, and the other is closed, in such a way that each of the points or outlines of this trace exactly masks the point or the corresponding outline in the subject to be represented.

The perspective of anything of which all the parts, whether real or imaginary, have known dimensions and occupy known positions can be obtained by relatively simple geometrical constructions. Conversely, if a perspective contains the images of certain known objects, it is possible to deduce from it the dimensions and the relative positions of other unknown objects whose images figure in that perspective.

Such a perspective regarded by one eye only from exactly the position of the viewpoint would appear to us, at least as far as the forms are concerned (without considering colours and brightness), just as the object represented would appear when viewed from the corresponding point, the same outlines being seen in the same relative positions.

In conformity with this definition, the surface of a projection plane only plays the rôle of an open window through which appears the landscape or the scene which was represented.

27. If we consider an object (Fig. 5.1) which for clearness has been purposely chosen of simple form, a viewpoint O , and a vertical plane T , then the perpendicular OP dropped to the plane from the viewpoint meets the plane at a point P

(called the *principal point*), the distance OP being the *principal distance* of the perspective obtained.

Any group of straight lines parallel to one another and to the plane of projection will be reproduced in the perspective by straight lines parallel to those considered. In particular, all vertical lines in the subject will be represented by vertical lines in the perspective.

Any groups of parallel straight lines which are not parallel to the projection plane will be represented in the perspective by a group of straight lines converging to the same *vanishing point*, which is defined by the intersection of the projection plane with a straight line dropped from the viewpoint parallel to the direction in question in the subject.

The vanishing points of all the horizontal lines are situated on the *principal horizontal* HH' , the intersection of the projection plane with the horizontal plane through the viewpoint and also (in this case of a vertical projection plane) through the principal point P .

In particular, all the horizontals contained in the façade of the shed (Fig. 5.1), or parallel to this façade, are represented by straight lines which converge to the vanishing point F , defined by the intersection of the plane of projection with the straight line OF dropped from the viewpoint parallel to the straight lines being considered in the subject. All other groups of lines parallel to the façade of the shed will have their vanishing points on the vertical line FG .

Once the *position* of the viewpoint and the *direction* of the projection plane have been determined, the perspective obtained is to a close degree independent of the principal distance. The perspectives obtained from a single viewpoint but on several parallel planes are geometrically similar; any one can be changed into any other merely by proportional amplification or reduction; for example, by means of a pantograph. The principal distance only affects the *scale* of the images, which all vary proportionally.

28. Deformations due to Displacement of the Viewpoint. When a perspective is looked at from a point other than its viewpoint, the different parts of the image are no longer seen at the same angles as the corresponding parts

of the subject. The representation in this case is falsified, and one no longer appears to see the object but only a more or less distorted form of it.

If we suppose at first that the eye with which

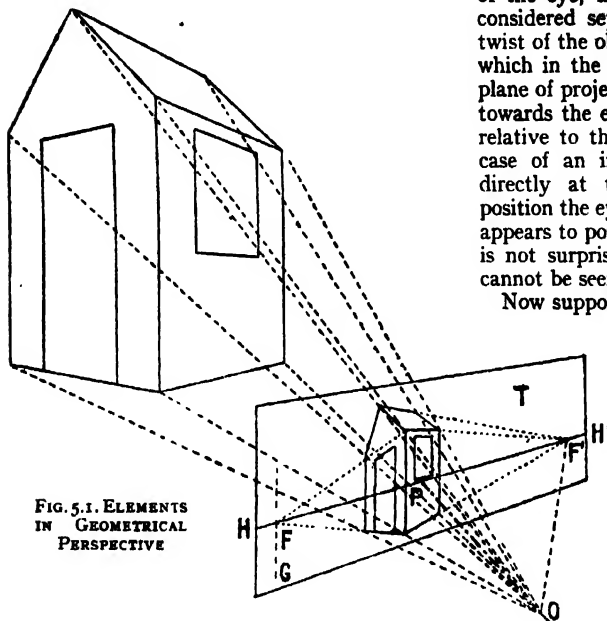


FIG. 5.1. ELEMENTS IN GEOMETRICAL PERSPECTIVE

the perspective is observed remains at a distance from it equal to the principal distance, but without being placed at the viewpoint, the object undergoes a twist. For example, if the eye is in a position higher than the viewpoint, all the horizontals of the subject appear to slope down from the observer to the horizon; their vanishing points become in fact lower than the eye, and the apparent slope of each horizontal will be that of a straight line joining the eye to the corresponding vanishing point.

Next, suppose that the eye, while remaining at a distance from the projection plane equal to the principal distance, is displaced laterally. To make this clear, suppose it is placed opposite the vanishing point F (Fig. 5.1). This point, being now substituted for the principal point, would be on a perspective examined under correct conditions, the vanishing point of the straight lines of the subject perpendicular to the projection

plane. Under the actual conditions of examination one is thus led to consider the façade of the shed as perpendicular to the plane of projection, which is not the case.

Every combination of the two displacements of the eye, the effects of which we have just considered separately, will result in a double twist of the object. Notably, the straight lines, which in the object were perpendicular to the plane of projection, will appear always pointing towards the eye, whatever may be its position relative to the projection plane. Consider the case of an image of a rifle which is aimed directly at the viewpoint. From whatever position the eye views the image the rifle always appears to point directly at the observer, which is not surprising since the profile of the rifle cannot be seen.

Now suppose that the eye, whilst being kept on the perpendicular from the projection plane to the principal point, is displaced along the length of this line. The object will appear *drawn out* in depth or *compressed*, according as the distance of observation is greater or less than the principal distance, the deformation being in every case proportional to the ratio of these two distances. Imagine two objects at A and B in the horizontal plane (Fig. 5.2).

In the perspective traced from the viewpoint O on the projection plane T , the images of these two points are at a and b . If, instead of observing this perspective from its viewpoint, the eye is moved to O' , at double

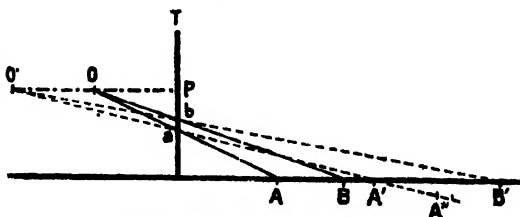


FIG. 5.2. DISTANCE AND PERSPECTIVE

the distance, obviously the objects cannot be considered as hanging freely in the air, but must be resting on the plane shown. One is, therefore, compelled to assign to these points the positions A' and B' , the object thus being drawn out in the ratio of 1 to 2. If

the distance AB is more or less fixed (the case of a man lying down to whom cannot reasonably be attributed double the normal stature), the details of the object situated at A' , which we intuitively consider as being at A'' , will be on an exaggerated scale for the position that we attribute to them in the object. The front planes are expanded relatively to the back planes.

Obviously, these deformations may occur in addition to those due to the displacement of the observer upwards or across. These deformations may sometimes be observed in "back projection" scenes in cinema films, in which a scene is enacted in a studio in front of a translucent screen on to which the image of an outdoor shot is projected.

29. **Normal Distance of Vision and Angle of Visual Field.** A normal-sighted person generally chooses a distance of 10 or 12 in. as the distance from his eyes at which to examine such objects as printed matter, etc. This distance is usually known as the *normal distance of vision*. The smallest distance of distinct vision at which things can be seen without any abnormal effort is rarely less than 6 or 8 in.; a normal eye can often see distinctly an object only from 4 to 6 in. away, but in such cases fatigue sets in so rapidly that this can only be done for a few seconds.

In order that the eye may perceive simultaneously all the objects represented in a picture, the latter must not be too extended. The angular field of the eye does not exceed about 50° , and we tend therefore when looking at a picture, to place our eyes at a distance not less than the diagonal of the print; the examination is probably easier at a greater distance than this within reasonable limits.

30. In order that a perspective may be examined with avoidance of the distortions described in § 28, it must be looked at from its viewpoint. The principal distance should then be at least equal to 10 in. (or, as an extreme, 8 in.), unless the picture is examined by means of a magnifying glass, which allows it to be brought nearer to the eye;¹ moreover, it is

¹ When an image is observed with a magnifying glass under conditions such that the image is at infinity (this condition is instinctively fulfilled by an observer of normal vision, or by one who keeps on his correcting glasses), the image is seen as it would be if the centre of rotation of the eye coincided with the optical centre of the glass. In order to examine under perfect conditions a perspective with a principal distance less than the distance of distinct vision, a magnifying glass must be chosen of which the focal length is equal to this principal distance. Incidentally, note that the magnification of a magnifying glass is expressed by a

essential that the included angle (angle between extreme rays converging to the viewpoint) does not appreciably exceed 50° .

If these conditions are not conformed with, the perspective can only be seen falsely. According to what has already been said, it can easily be realized that the tolerances in the position of the eye during the examination become greater the greater the principal distance. In particular, if the principal distance is at least equal to 10 times the mean separation of the eyes, there will no longer be a very marked difference between the objects as received individually by each of the eyes, and the binocular view of the picture will no longer cause any inconvenience.

31. **Anomalies of an Exact Perspective.** A perspective, traced directly on glass or resulting from correctly carried out graphical construction, is of necessity exact in the geometrical sense, but aesthetically it may be *picturesque* or *defective*, according to the value chosen for the principal distance and the included angle. If the eye can be placed at the viewpoint, it will obviously see an object identical with the object seen from the same viewpoint, but as soon as one moves from the normal position (and this will necessarily be the case if the principal distance is very short, or if the included angle exceeds the angle of the visual field) serious distortions will appear, especially towards the limits of the field. These distortions are due especially to the fact that the image projected on our retina is projected on to a sphere, a very different case from a plane perspective.

From whatever angle we may look at a sphere its outline always appears exactly circular. On the contrary, the plane perspective of a sphere is an ellipse, except in the case where the centre of the sphere is on the perpendicular from the viewpoint to the projection plane. As the visual ray to the centre of the sphere makes an increasing angle with this perpendicular, so the distortion also becomes greater.

Nevertheless, if one stands in front of a colonnade, all the columns appear the same diameter. If there is a difference, the columns farthest away appear somewhat smaller; in the perspective of a colonnade seen from the front, the images of the columns become larger as one moves farther away from the principal point.

quarter of the number expressing its converging power in diopters. Thus a glass of 8 diopters (focal length 25 mm) has a magnification of 2.

Fig. 5.3 (from an old paper by Moëssard), showing in elevation, in plan, and in perspective a series of identical vertical cylinders, each being surmounted by a sphere, is an excellent example of anamorphosis (i.e. a perspective which is displeasing, although correct), due to the fact that an excessive angle has been included (by means of the angular graduations given, the obliquities corresponding with different deformations may be seen). Distortion similar to that

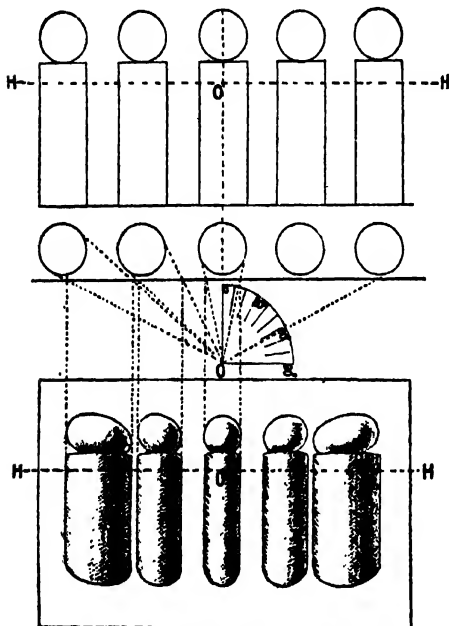


FIG. 5.3. WIDE-ANGLE PERSPECTIVE

of the spheres represented in Fig. 5.3 is often noticed in the faces of people photographed in the foreground under a relatively large angle (photographs of crowds, banquets, etc.).

The artist, painter, engraver, or draughtsman always modifies the strict laws of geometrical perspective by means of certain tricks of which the greatest masters have given examples. He generally limits the included angle to between 15° and 20° by choosing a principal distance somewhere between twice and three times the greatest dimension of the image. Further, even if he respects the laws of perspective whilst tracing the principal lines, he departs from them for the details, each object

being represented almost as if it were seen from the front. It can almost be said that the painter only adopts the plane perspective for the placing of the different elements, the tracing of these resulting from the drawing on the plane of their spherical perspectives.

Notice, however, that the observer who can only see with one eye and who cannot move, though provided for by the theorists of perspective, is not found amongst Nature artists, who always judge their effects with both eyes open, and frequently move about so as to look at their picture from points far removed from the actual viewpoint; by doing this they can correct the anomalies which would show to badly-placed spectators. This explains why pictures in museums can be examined from very different positions, and often even abnormal positions, without appearing displeasing. Unfortunately, this wide tolerance is not found in the examination of a perspective, unless its principal distance is very great and the included angle very small.

32. Influence of Choice of Viewpoint. The choice of viewpoint affects the aspect of the

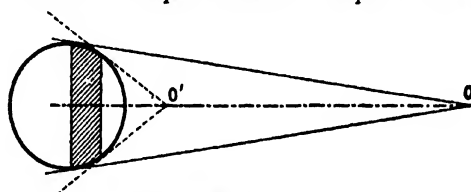


FIG. 5.4. EFFECT OF VIEWPOINT ON PERSPECTIVE

image of each of the different objects and at the same time the ratio of the respective sizes of the images of objects situated at different distances.

Consider the case of a sphere (Fig. 5.4), and let us determine the perspectives from the two viewpoints O and O' . It will be realized at once that, seen from very near, the sphere will show only a small fraction of the surface which can be seen from a farther distance away; all the shaded zone will be seen from O and not from O' . It can be seen that if we substitute for the sphere a human face seen from the front, then from the viewpoint O' the ears will be hidden, and the mouth (the size of which is about one-quarter of that of the whole face) will occupy a third of the apparent diameter and seem to be enormous.

Now consider the case of two objects of the same dimensions situated at different distances

from the viewpoint, in the same direction. If the nearer of the two objects is at a distance from the viewpoint equal to n times the distance between the objects, the respective scales of their images will be in the ratio $n/(n+1)$. Thus the images will be less different as n becomes greater, as is shown in the following table, where the values of $n/(n+1)$ are given for different values of n .

$n/(n+1)$	1	2	3	4	5	10	20	100
	0.50	0.66	0.75	0.80	0.83	0.90	0.95	0.99

Thus it can be seen that if the distance of

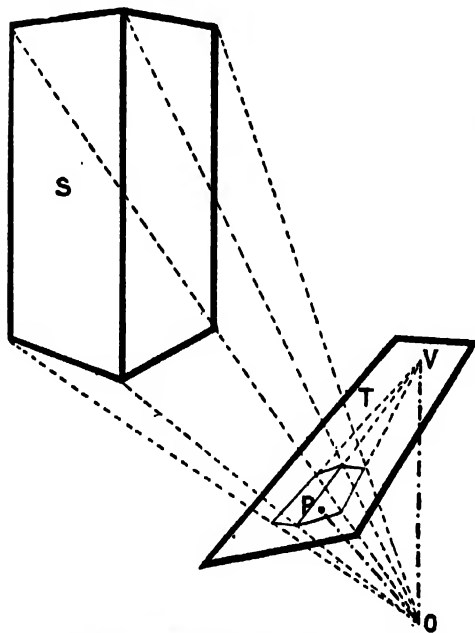


FIG. 5.5. PERSPECTIVE ON AN INCLINED PLANE

two equal objects is equal to the distance of the nearer of them from the viewpoint, one of the objects will be represented twice the size of the other. If we multiply by ten the distance to the first of the objects, and compensate for this increase of distance by extending the principal distance until an image of the nearer object is obtained which is the same as previously, the more distant object will not differ from it more than 10 per cent. An example of this may be seen in telephoto pictures, particularly of cricket matches, where the two batsmen

are about 20 yards apart and the viewpoint may be 200 yards away.

Returning now to the case of the front view of a portrait, and bearing in mind that the point of the nose is about five inches in front of the back outline of the ears, it can be calculated that in a portrait taken at about four feet from the sitter, a rigorous application of the laws of perspective would result in the nose being represented on a scale greater by 10 per cent than the scale of the ears. A painter, when sketching a portrait, is always at least 10 or 15 ft from his model.

Let us take the case of a house, and consider its perspective at a distance of about 300 yd. At this distance the house is in correct relation with the distant landscape. If now we approach to within 20 yd of it, whilst keeping the same principal distance, the image of the house will be magnified 15 times, but the distance will be practically the same size as before, and will thus be on a much smaller scale.

Similarly, a painter, when prevented from going back far enough to see properly, would design the background on a magnified scale in order to correct this effect, which, though it would be scarcely noticeable in the examination of a landscape itself, because our brain corrects the sensations which our eyes transmit to it, might be displeasing in the case of a plane image.

33. Binocular Vision. Only a rough idea of the relative distances of objects can be obtained by monocular vision (using one eye only). One knows how difficult it is to place a finger in the neck of a bottle placed by someone else at the height of the observer's eyes, when one eye is shut. The factors to be appreciated are the variation of the apparent dimensions of an object of known size, the changes in the relative position of the objects when the observer moves transversely, the aerial perspective (§ 17), and the variations in the effort necessary to accommodate the eye (*focusing the eye*) according to the distance of the object. Chromatic aberration of the eye also plays an appreciable part in the estimation of distances, images being bordered with a red or blue fringe according to whether the corresponding objects are nearer or farther than the plane on which the eye is focused.

The causes which give rise to the sense of relief in *binocular vision* (using two eyes) are, on the one hand, the dissimilarity of the two retinal images, each eye seeing a single near point projected on two different points of the

background, and on the other hand, the effort of convergence of the ocular axes towards the fixed point, this effort becoming greater as the point becomes nearer. These two factors are important only for relatively near objects; when viewed from the air from only a few thousand feet, objects on the ground lose their relief.

Consider two perspectives of a single subject, each perspective having the same principal distance, on two parts of the same plane, from two viewpoints the separation between which is equal to the mean separation of the eyes (about 65 mm). If the centres of rotation of one's eyes be placed at the viewpoints, each eye only seeing the perspective of its own viewpoint, the same sensation of relief will be experienced as in direct observation of the object with the two eyes (the variations of the accommodation no longer obtain in this case). This relief may be so striking that an observer who did not already know would scarcely believe that the solid image which he could see was actually the result of two plane images.

This fact forms the basis of *stereoscopy*. Stereoscopic vision implicitly assumes that the observer has two equal and symmetrical eyes.

34. *Perspective on a Non-vertical Plane.* If from the viewpoint O (Fig. 5.5) the perspective of a solid body S be drawn on the non-vertical plane T , the images of all the vertical lines of the solid will converge to the vanishing point V , where V is the intersection of the plane T with the vertical dropped from the viewpoint.

In presenting this plane under the same obliquity to an observer whose eye, placed at O , would be forced to look in the direction of the principal point P , especially in the absence of external marks which would indicate to him the obliquity of the plane on which was the perspective, he might have the illusion of the object represented. But an observer who did not know, examining such a perspective under the same conditions as he would regard a normal one, would be led to conclude that the solid object represented was not a parallelepiped, but a truncated pyramid. He might, not unnaturally, conclude that the solid figure was represented as in the act of falling.¹

A vertical plane of projection is the essential condition for the reproduction of vertical lines as verticals in the perspective.

¹ We are not envisaging here the case of views intentionally taken looking downwards or upwards for documentary purposes or in order to achieve some special effect.

Experience shows that once the perspective has been drawn under these conditions, the projection image can then be shown obliquely without its being displeasing (the case of pictures hung rather high in such a way that their viewpoint is at the height of the observer's eyes when standing), though from the moment when we realize this obliquity we should not consider as admissible the representation of an object on an inclined surface, even if this was viewed under its normal inclination.

35. *Panoramic Perspective.* In cylindrical perspective, known as panorama, the viewpoint is situated on the axis of the cylinder of revolution (vertical cylinder), which constitutes the

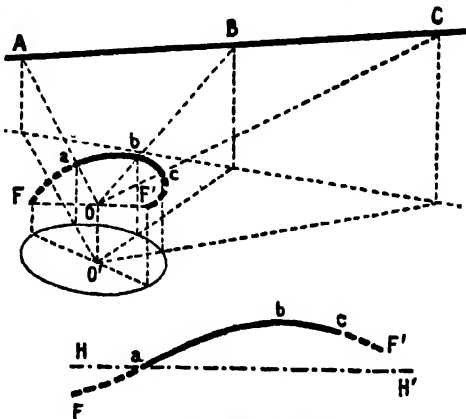


FIG. 5.6. PANORAMIC PERSPECTIVE

projection surface. In this system of perspective, verticals are represented by verticals, the horizon line by a meridian circle, and all other straight lines by ellipses. When the projection surface is maintained in its cylindrical form and looked at from the viewpoint, what is seen is identical with the subject, but if the projection surface is now unrolled and becomes a plane, all the straight lines of the subject, with the exception of the verticals and the horizon line, are represented by curves. Thus it is, for example, that the straight line ABC (Fig. 5.6) is represented in the panoramic perspective, after this has been flattened out to a plane, by the curve abc , with vanishing points at F and F' , which are common to the perspectives of all other straight lines parallel to that considered.

Such deformations are obviously a drawback in cases where it is desired to represent subjects

containing numerous straight lines other than the verticals, such as architectural works or views of towns having straight streets. But the suppression of all deformations due to excessive obliquity of the visual rays relatively to the projection of plane perspectives (§ 31, Fig. 5.3) gives to panoramic photographs, often limited to a fraction of the complete horizon, a special interest in such cases as the representation of a very extensive landscape, for example high mountainous country, or of a large number of people.

Due to its being unfolded to give a plane surface, such an image no longer permits of *one* viewpoint only, but of an *infinite number* of them, arranged on a straight line parallel to the horizon line, at a distance from the image equal to the principal distance. Such a projection should be considered as the combination of a great number of projections each formed from a straight vertical band, each to be examined from its particular viewpoint. The observer moving in front of the projection should thus only look at the details of the image which he sees exactly opposite to him.

36. Sharpness of Vision. Sharpness of vision, or visual acuity, which varies from individual to individual and with the lighting conditions, is measured by the distance from centre to centre of black parallel lines of equal width, separated by white spaces of the same width,

this distance being expressed as a fraction of the greatest distance at which the lines can still be separately seen when viewed closely, i.e. when their images are formed on the most sensitive part of the retina. A good eye can distinguish two lines the distance apart of which measured from centre to centre corresponds to an angle of 1 minute. This would be given by a distance of $1/250$ in. at 12 in. Practically, the sharpness of an eye is considered to be about the average when it can separate lines $1/250$ in. apart at a distance of 8 in., corresponding with an angle of $1/2,000$ radian.

37. Depth of Field of the Eye. When the eye is accommodated for regarding an object at a certain distance with maximum sharpness, objects nearer and farther away do not give sharp images on the retina. There exists, however, a certain zone within which all objects appear to the eye with the same sharpness. The depth of this zone is known as the *depth of field*, which becomes greater as the object viewed is farther away.

In fact, in looking at a scene of which the different elements are at very different distances from the observer, the accommodation varies constantly as the eye concentrates on the various points. Thus, in the average sensation which results, the most important points are seen more sharply than those of only secondary interest, which are, as it were, only seen accidentally.

PART 2

THE OPTICAL IMAGE BEFORE PHOTOGRAPHIC RECORDING

CHAPTER VI

THE CAMERA OBSCURA AND PINHOLE PHOTOGRAPHY

38. The Camera Obscura. The camera obscura (Fig. 6.1) appears to have been known at a very early date. According to Eder's *Jahrbuch für Photographie*, it was mentioned by Ibn al Haitam in 1038. In one of his undated manuscripts, the celebrated painter, engineer, and philosopher, Leonardo da Vinci, who died in 1519, describes this phenomenon in the following way: "When the images of illuminated objects enter a very dark room through a very small hole and fall on a piece of white paper at some distance from the hole, one sees on the paper all the objects in their own forms and colours. They will be smaller in size and will appear upside down because of the intersection of the rays. . . . A suitable hole can be made in a very thin plate of iron."

Outside the room each illuminated point, scattering the light in all directions, sends through the aperture a beam of light in the form of a very narrow cone. This cone has its apex at the object point in question, and its base is that of the aperture. Thus it illuminates the scattering or translucent screen on which it is received by a small spot, which is thus the image of the point object.

Within certain limits, the spot formed by the projection of the aperture on the screen will become smaller, and consequently the whole image sharper, as the aperture itself becomes smaller and as the material in which the aperture is made is thinner. The image will also become sharper as the aperture is moved farther away from the screen. In fact, under these conditions, the sizes of the individual spots increase much less quickly than the dimensions of the image. Such images sometimes occur unintentionally on photographic plates as parasite images or "doubles," when there happens to be a small hole in the outside wall of the camera, such as a screw-hole which has not been stopped up.

The camera obscura was much improved in the second part of the sixteenth century by fitting a biconvex lens at the aperture. In the

early part of the eighteenth century it was developed into a portable instrument similar to our present-day cameras, and was frequently used by artists as a means of making sketches from Nature.

39. Identity of the Camera Obscura Image with an Exact Perspective. In 1568 D. Barbaro recommended the use of the camera obscura for automatically making perspective drawings.

Suppose that a sheet of glass is placed in front of the camera, parallel to the screen, so that the glass plate and screen are equidistant from the aperture. The perspective on the glass plate, with the aperture as viewpoint, will be identical with that on the screen from the same viewpoint (Fig. 6.2), as may be shown by simple geometry.

40. Pinhole Photography. Although not much practised in recent years, pinhole photography can give very useful results in the case of inanimate objects; it even yields images under conditions in which it would be impossible to get comparable results with the objectives now available (Méheux, 1886).

In order to obtain an image of sufficient sharpness it is an advantage to use an aperture of the smallest possible diameter in a very thin plate, since a thick plate would restrict the field due to vignetting (cf. § 56) and would decrease the contrast due to reflections from the cylindrical surface of the aperture. A simple experiment, such as forming the image of a luminous filament of an electric lamp, shows that with each distance of the object from the camera there corresponds, for a given diameter of the aperture, a distance from the aperture to the receiving screen (e.g. a mat glass) at which the greatest possible sharpness of the image is obtained. When the distance of the object is large compared with the distance from the aperture to the screen, the diameter of the "disc of confusion" which is formed as an image of each point in the object, is at least equal to the diameter of the pinhole. Because of diffraction by

the edges of the aperture, each point in the object is imaged as a diffraction pattern, the size of which decreases as the aperture increases. The first phenomenon is more important when the aperture is large, and the second when the aperture is small.

Thus according to the laws of geometrical optics, the diameter D of the image of a point is given by $D = d$ where d is the diameter of the pinhole.

According to physical optics, however, the effective diameter of the image of a point source is given, approximately, by

$$D = \frac{2f\lambda}{d}$$

where f is the distance from the aperture to the screen, and λ is the wavelength of light. The optimum conditions are found when the diameter as given by geometrical considerations is equal to that given by considerations of physical optics. Thus

$$d \approx \frac{2f\lambda}{d}$$

whence the optimum distance f is given by

$$f \approx \frac{d^2}{2\lambda}$$

Taking $\lambda = 0.0005$ mm, $f \approx 1,000d^2$; Abney and Dallmeyer both found $f = 625d^2$, and Colston and Coombes both found $f = 1,250d^2$.

In the case where it is desired to photograph very near objects the optimum extension is calculated in just the same way as when using an objective of focal length f under the same conditions (§ 63).

The sharpness of images photographed in this way, when the conditions are properly adjusted, is quite comparable to that of images given by soft-focus lenses, and particularly by lenses which are not chromatically corrected.

A considerable angle of field can be covered by a pinhole, which can thus be advantageously used for photographing monuments in cases when it is not possible to go a sufficient distance away.

The one disadvantage of this process is the relatively long exposure required. This, however, is of considerably less account now that we have at our disposal plates of such extreme sensitivity.

41. Making a Pinhole. It is not very easy to obtain commercially metal plates having calibrated holes with clean edges suitable for pinhole photography.

In order to make such a circular aperture in a

piece of metal foil it is best placed on a strip of soft wood or on a piece of lead, and a needle used as a punch. The needle should be stuck through the centre of a cork along the axis of the latter, cut off flush with one end, and the other end of the needle then cut about 1/25 in. from the other surface of the cork. This projecting end must be in the parallel cylindrical part of the needle. Now rub the protruding end on an oilstone until a plane and polished end with sharp edges is obtained. The hole is then made

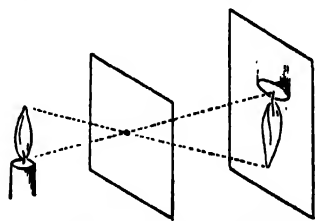


FIG. 6.1. FORMATION OF THE IMAGE IN A PINHOLE CAMERA

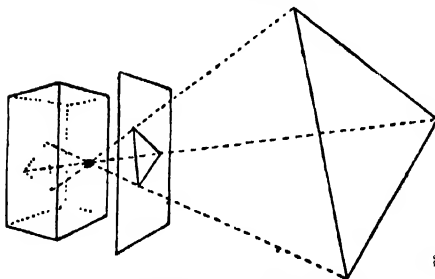


FIG. 6.2. PERSPECTIVE RENDERING BY A PINHOLE CAMERA

in the metal foil by giving the top of the cork a sharp blow. The edges of the hole thus made should be examined with a strong magnifying glass, and, if necessary, made perfectly smooth by means of the finest emery paper. To render it permanent, the metal foil may now be mounted between two cards.

The aperture made in this way may be fixed to the front of a camera or any light-tight box which can be loaded with a plate or film. A card running in grooves makes a sufficiently good shutter, since the necessary exposures are long. The image given by a pinhole is generally so faint that it cannot be easily examined on a ground glass screen. In order to find out the width of field which the pinhole gives, an aperture of about 1/4 in. diameter may be temporarily substituted for it, or, failing this, a spectacle

lens of focal length equal to the distance previously ascertained as optimum distance between aperture and screen for photographing distant objects.

A number of applications of the principles of pinhole photography have been made in different fields.

A small camera with four pairs of pinhole apertures has been used for photographing the internal walls of the stomach (J. Heilpern and F. G. Back, 1928), and a high-speed cine camera (120,000 frames per second), utilizing

pinhole apertures has been applied to the study of arcing in industrial circuit-breakers (D. C. Prince and W. R. Rankine, 1939).

The principles of pinhole photography are often used in radiography. A small hole in a lead foil is first covered with black paper, and an exposure made by X-rays. The paper is then removed, and another exposure made by white light. The positions of parasitic images can thus be located.

The principles of the pinhole camera have been recently discussed by E. W. H. Selwyn.

CHAPTER VII

GENERAL PROPERTIES OF OPTICAL SYSTEMS: ABERRATIONS

42. Lenses. Lenses are masses of glass, bounded, by successive moulding, grinding and polishing operations, by two spherical¹ surfaces, or a spherical and a plane surface. According as the beam of light emerging from a lens held up to the sun has a diminishing or increasing cross-section, the lens is said to be *convergent* or *divergent*; convergent (or *positive*) lenses are thicker at the centre than at the edge (Fig. 7.1 I to III); on the other hand, the edges of divergent (or *negative*) lenses are thicker than the centre (Fig. 7.1. IV to VI).

The *optic* (or *principal*) axis of a lens is the straight line joining the centres of the two spherical surfaces, or, in the case of lenses having one surface plane, the perpendicular on to that surface from the centre of curvature of the other. In every combination of lenses the optic axes must coincide; this is known as a *centred system*.

43. Images Formed by Convergent Lenses. The elementary teaching of optics assumes an ideal simplicity in the instruments studied which is quite artificial (lenses of zero or negligible thickness; rays at small inclination to the axis passing through the lenses close to the axis, etc.). These mathematical fictions can only with difficulty be applied to the complex system of the photographic lens, often working at a very large aperture over a very extended field; it is all the more necessary to call attention to this point, as the application of the rules thus simplified may lead, by mathematical deductions which are strictly logical but ill-founded, to grossly erroneous conclusions.

When a convergent lens is placed at a suitable distance from a luminous object (or more generally any well-lit object, stray light being excluded) it forms an inverted image which can be received sharply on a screen placed at a determined distance from the lens, this screen being, for example, a piece of white paper

¹ Lenses are often made for sight-correction with toroidal and cylindrical surfaces, and in recent years photographic and other lenses have been made with paraboloidal, ellipsoidal, and other aspherical surfaces. It may be added that many lenses in everyday use (such as some magnifiers, condensers, etc.) are not ground and polished but are made by moulding the glass in polished moulds.

viewed by reflected light, or ground glass viewed by transmitted light.

A simple lens (reading-glass of large diameter or condenser lens), when used to project the image of a window on white paper pinned to the opposite wall but placed not exactly opposite to the window, provides an excellent lesson in optics. The image is rather poor, being spoilt by a number of defects or *aberrations* (the only optical instrument that can give perfect images is the plane mirror). The images of the bars will show rainbow colours



FIG. 7.1. TYPES OF LENS ELEMENTS

I Biconvex lens	} Positive lenses
II Plano-convex lens	
III Convergent meniscus	
IV Divergent meniscus	} Negative lenses
V Plano-concave lens	
VI Biconcave lens	

(*chromatic aberration*), and even if this aberration is removed by viewing through suitable coloured filters, the image is not sharp (*spherical aberration* due to the spherical form of the lens surfaces). The image can be improved by covering the lens with an opaque paper pierced with a circular hole smaller than the lens (*diaphragm* or *stop*), but is then not so bright. Further, it is seen that the images of the bars are more or less curved (*distortion*), the curvature varying with the position of the diaphragm. The lens requires to be moved towards or away from the paper in order to bring the centre and edges of the image successively into focus (*curvature of the field*). Finally, the image of the vertical bars is not sharp at the same time as that of the horizontal bars, especially at the edge of the image (*astigmatism*).

44. Real Images—Virtual Images. An optical image (such as we have considered in the previous paragraph), capable of being received on a mat screen, is called a *real image*.

When a convergent lens is placed at too short

a distance from an object, it is impossible to form a real image of the object at any position of the screen, but on looking through the lens an upright, magnified image of the object is seen. Such an image, visible only through the lens by an observer looking in the direction of the object, is called a *virtual image*. All the observational instruments (telescopes, microscopes, etc.), adjusted for an observer with normal sight, give virtual images.

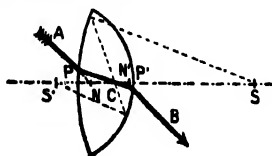


FIG. 7.2A. OPTICAL CENTRE
IN LENS

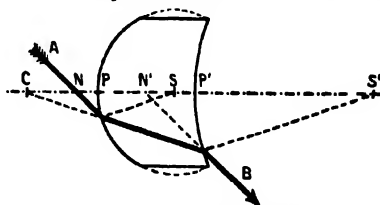


FIG. 7.2B. OPTICAL CENTRE
OUTSIDE LENS

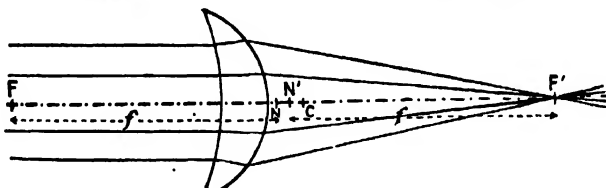


FIG. 7.3. FOCUS AND FOCAL LENGTH

A divergent lens can give only a virtual, upright, diminished image of a real object, at a position closer to the observer than the object. This property is utilized in the construction of "direct vision" view finders.

45. Optical Centre—Nodal Points. The optical centre of a lens is a point on its axis such that any ray within the lens which passes through it, or is directed towards it has its external parts (i.e. the continuations of this ray in the air) parallel to each other. This may be seen in Fig. 7.2A and 7.2B, in which two parallel radii have been drawn, one for each surface. If the tangents are drawn at the point of intersection of each radius with its own surface, these tangents will also be parallel, and it will be realized that a ray which joins these two points must have its external parts also parallel to each other.

The ray AB in Figs. 7.2A and 7.2B does not pass through these points of intersection, but is another example of a ray which suffers displacement but not deviation. It will be seen that the optical centre can lie either inside or outside the

lens. Note that the lenses drawn in Figs. 7.2A and 7.2B have the same radii of curvature, and the same distance (SS') between centres.

The nodal points¹ N and N' in Figs. 7.2A and 7.2B are the points in which the external parts of the ray would meet the axis if continued. In a perfectly corrected system these points, called the *front* and *rear* nodal points respectively, are fixed, whatever the direction of the rays considered. In other words, any ray

which is directed towards the front nodal point appears to emerge from the rear nodal point. Each nodal point can be regarded as the image of the optical centre produced by one of the surfaces of the lens, and each nodal point can be considered as the image of the other nodal point formed by the complete lens.

The intersections PP' of the surfaces with the axis are sometimes called the *poles*.

46. Foci—Focal Length. The image of an infinitely distant point (e.g. a star) towards which the optic axis of a lens is pointed, is the *focus* of that lens. From considerations of symmetry this is necessarily situated on the optic axis. As the lens can be turned with either face to the point-object, it possesses two foci F and F' (Fig. 7.3). In the case of a convergent lens the foci are the nearest points to

¹ Where the exterior surfaces of an optical instrument are bounded by the same medium (air in the case of a photographic lens) the nodal points are identical with the *principal* or *Gauss* points. This is not the case with an immersion microscope objective where the outside surface touches a liquid in contact with the preparation.

the lens at which a real image can be formed of a real object. The word "focus" (Latin: hearth) recalls the use of "burning glasses," the concentration of rays being a maximum in the neighbourhood of the focus so that tinder or other inflammable material can be ignited there when the lens is directed towards the sun.

When the two surfaces of the lens are in free contact with the air, the distance of each of the foci from the corresponding nodal point is the

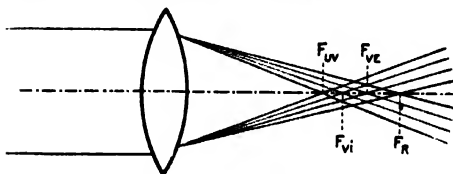


FIG. 7.4. CHROMATIC ABERRATION

same; this distance ($NF = N'F'$) is called the *focal distance* or *focal length*. For a rough approximation and where a thin lens is considered, the nodal points can be ignored and the focal length reckoned from the optical centre C . In many lenses the optical centre is close to the diaphragm. Telephoto lenses are the chief exception.

The focal length of an optical instrument is one of its essential characteristics.

47. Chromatic Aberration. The refraction of a ray of light passing from one medium to another (from air to glass, or vice versa) at non-normal incidence has not the same value for different colours. Therefore, when a beam of white light (§ 1) traverses a lens, the sharp images formed by light of different colours do not coincide. The rays which are refracted most, ultra-violet and violet, form their images nearer to the lens than those which are refracted less, orange and red.¹ (Fig. 7.4.) There is thus an infinite number of images each corresponding with one of the component radiations. In particular the position of the foci (images of infi-

nitely distant points on the axis) and of the nodal points (images of the optical centre) vary with rays of different colours, as does also the focal length.

The practical consequence of this is that whatever be the position of the viewing screen or the photographic plate on which the image is to be recorded, the sharp image corresponding with the apex of one of the cones is surrounded by bright rings corresponding with sections of all the other cones. If the position of the screen has been determined visually, and if the image is photographed with it in the same position, the phenomenon can give rise to an unsharp negative. The focus chosen is the best for the yellow-green images, which are the brightest visually, but in those cases where only blue-sensitive materials are used the position of best focus lies in the plane of the violet image. This defect is sometimes referred to by saying that such a lens possesses a *chemical focus* as distinct from the visual focus.

This inconvenience can be minimized when using non-colour-sensitive materials by displacing the photographic plate by the correct amount after visual focusing, or by using, both for focusing and photographing, a coloured filter which transmits only a small portion of the spectrum. Generally it is preferable to correct the chromatic aberration more or less completely by the use of at least two glasses of different characteristics, usually a crown and a flint, the use of different material allowing the images formed by two different colours to be united. Lenses for photography are generally corrected for D (yellow) and G (blue-violet) rays of the solar spectrum, and are then called *achromatic* (from Greek, meaning colourless). For some work, in particular colour photography, such a correction is insufficient, and coincidence of the nodal points and foci for three different colours is aimed at, generally by the employment of at least three glasses. A lens so corrected is called *apochromatic* (as defined by Abbe, an *apochromatic* objective should also be *aplanatic* (§ 48) for two colours).

Fig. 7.5 shows the position of focus plotted against wavelength for three different types of lens. The mean focal plane is indicated by the line PP' and the letters A, B, C, D, E, F, G represent the positions of the *Fraunhofer* lines on the wavelength scale.

Achromatic and apochromatic lenses are not usually corrected for infra-red. When photographing with infra-red emulsions it is therefore

¹ Calling n the mean refractive index of glass and n' and n'' the values of the index for the two rays considered, the difference of focal length ($f' - f''$), expressed in terms of the mean focal length f , is $f' - f'' = \frac{n' - n''}{n - 1} \cdot f$ (longitudinal chromatic aberration).

Considering the spectrum lines G and E (corresponding with the maximum photographic activity on ordinary plates and the maximum physiological activity respectively), this expression represents about 0.14 per cent of the focal length for *crowns* and 0.16 per cent for *flints*, the general designations of two classes of optical glasses.

necessary to rectify the focusing, this correction being made once and for all by methodical trial and error for each lens. As a rule the extension of the camera must be increased, after visual focusing, by 0.3 to 0.4 per cent of its value.

In addition to the above correction for *longitudinal chromatic aberration* or *axial chromatism*, some correction is usually also needed for *transverse chromatic aberration* or *lateral chromatism*. This error appears as images of varying size for different colours and is of some seriousness in the making of separation negatives for colour photography (Chapter LII), where the three images must all be of exactly the same size.

For the study of other aberrations we shall suppose that chromatic aberration is eliminated by means of a colour filter.

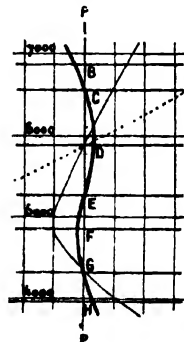


FIG. 7.5. CHROMATIC ERROR OF VARIOUS LENSES

— Apochromatic
- - - Achromatic
..... Non-achromatic

from the central zone to the edge. For any position of the screen or photographic plate between the extreme foci F and F'' (Fig. 7.7), the image of a luminous point will be a circle, the brightness of which diminishes from the centre to the edge. The points of intersection of successive pairs of rays determine a surface, the form of which resembles the bell of a trumpet, along which there is a concentration of light. This can be observed, for reflected light, on the surface of liquid in a teacup, and is called the *caustic* of the beam.

This aberration may be reduced by the choice of suitable curvatures¹ for the surfaces, but the

¹ Spherical aberration is at a minimum for a biconvex lens of which the surface on which the light is incident has a radius of curvature $\frac{1}{2}$ that of the surface of

astigmatism (§ 49) will be increased; also the aperture may be reduced, but this will reduce the speed (§ 89); moreover, if the diaphragm is not close to the lens, rays of different obliquity pass through different zones of the lens, thus increasing the *curvature of field* (§ 52).

As a rule, spherical aberration is corrected by making the images produced by two zones of the lens coincide, generally the central zone and the extreme (marginal) zone, or one close to it. This correction, obtained by combining at least two different glasses of suitable shape, does not hold for intermediate zones. In order to show the importance of residual aberrations a curve is drawn in the principal section, of which each point is defined (Fig. 7.8) by the intersection of the incident ray with a line drawn perpendicular to the axis through the corresponding focus. It is usual to magnify the scale of the intersection distances for convenient reading.

An optical system rigorously corrected for this aberration is said to be *aplanatic* (Greek = free from error). Owing to the syllable—*plan* this term is often confused with freedom from curvature of field. As a matter of fact, no photographic lens is rigorously aplanatic. It is

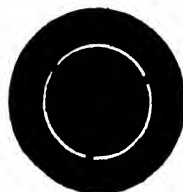


FIG. 7.6. DIAPHRAGM TO SHOW SPHERICAL ABERRATION

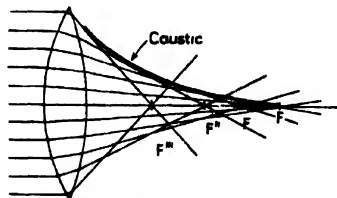


FIG. 7.7. SPHERICAL ABERRATION

possible to correct spherical aberration only for certain object distances, which are selected as being those at which the lens will most frequently be used, according to the purpose for which it is designed. In practice, the correction is sufficient for most requirements at intermediate distances. We shall see, however, that the residuals of this aberration determine the distortion of the image.

emergence (for glass of mean refractive index 1.5). This minimum aberration is only 6.4 per cent of that of an equiconvex lens of the same focal length. Spherical aberration is at a maximum in the case of a meniscus.

49. Astigmatism. Astigmatism (Greek = absence of point) is an aberration which is seen in oblique rays and arises from the asymmetry of the refraction in different sections of the beam; the most obvious effect is the concentration of light into two distinct foci.

This effect may be understood, at least

the screen is in contact with the lens); ellipses, becoming flatter and flatter with their long axes in the meridian plane, which degenerate to a short straight line in that plane; ellipses orientated as before but becoming more and more circular; a circle; ellipses getting flatter and flatter, with their long axes in the sagittal plane;

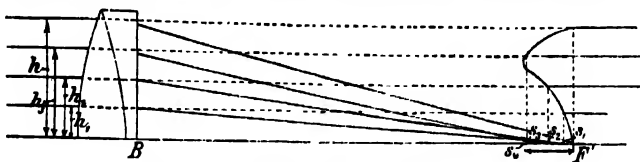


FIG. 7.8. CHART OF SPHERICAL ERROR

qualitatively, by studying Fig. 7.9A and 7.9B. Imagine a cylindrical bundle of rays with AA' as axis, striking the lens at an oblique angle. The section of that bundle which lies in the plane of the diagram (*meridian section*) will be refracted as shown in Fig. 7.9A. The section of the bundle which is at right-angles to the plane of Fig. 7.9A encounters surfaces of greater curvature: in fact it encounters a section on $A'B'$, which is shown in Fig. 7.9B and is called the *sagittal section*. The point B , to which the rays of the meridian section converge, is then

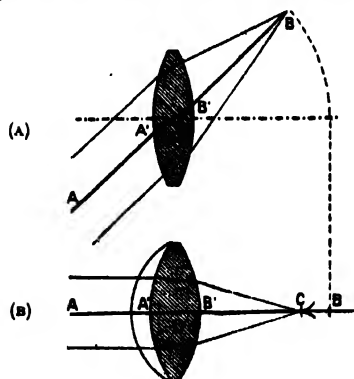


FIG. 7.9. ABERRATION OF OBLIQUE (A) AND AXIAL (B) RAYS

farther from the lens than the point C , to which the rays in the sagittal section converge.

If a screen (white paper, ground glass, etc.) is held perpendicular to the optic axis and gradually moved away from the lens, the beam emerging from the lens and originating in a single point source will describe on the screen successively the following shapes: a circle (when

a short straight line in the sagittal plane; ellipses again. This experiment can be best carried out by using one of the elements of a condenser. Fig. 7.10 represents this succession of "images" of a point source of light, considerably exaggerated. The focal lines R and T are called *radial* (or sagittal) and *tangential* (or meridional) respectively.

50. Tangential and Radial Images. If one tries to form an image of a wheel, the centre of which lies on the axis of the lens, it is found that it is impossible, in the presence of astigmatism, to form a sharp image of the spokes (radial lines) at the same time as a sharp image of the rim (which represents an infinite series of small tangential lines) (Fig. 7.11), for at the position of the radial focal line (Fig. 7.10) only the spokes will be sharp, and in the position of the tangential focal line only the rim of the wheel will be sharp. If the two focal lines are not widely separated from one another, a more or less sharp image of all parts of the object will be found at the intermediate position where the pencil gives a circular patch (*circle of least confusion*, C , Fig. 7.10).

The locus of the radial images of infinitely distant points (e.g. stars) given by a lens is a surface S_r (Fig. 7.12), which (at least in the central region) is generally concave to the lens; the tangential images lie on another surface S_t , generally less curved than S_r . These two surfaces (*focal surfaces*) have a point of contact at the paraxial focus F .

The radial and tangential images of points in any plane perpendicular to the optic axis form analogous surfaces.

In order to represent the astigmatism of a lens, a graphic method is used similar to that already employed for spherical aberration (Fig. 7.8). The displacements of the two focal surfaces

(multiplied by four to facilitate reading of the curves) for a lens of 4 in. focal length are plotted on the horizontal scale, while the angle made by the secondary axis with the principal axis is plotted vertically on the scale of 0.1 in. to the degree. Figs. 7.13A and 7.13B from von Rohr, show respectively the astigmatism curves for a lens partly corrected for astigmatism (Orthostigmat type II) and for one well-corrected (Planar).

Correction of astigmatism is only possible by the employment of at least three separated lenses, or, if the lenses are to be cemented in groups, at least four lenses of different material. Two at least of the glasses must form what is called an *abnormal pair* in which the refractive

reduce the curvature of field and astigmatism for a given obliquity between the principal and secondary optic axes (for example 20°), the astigmatism being sufficiently small at other obliquities to be relatively unimportant.

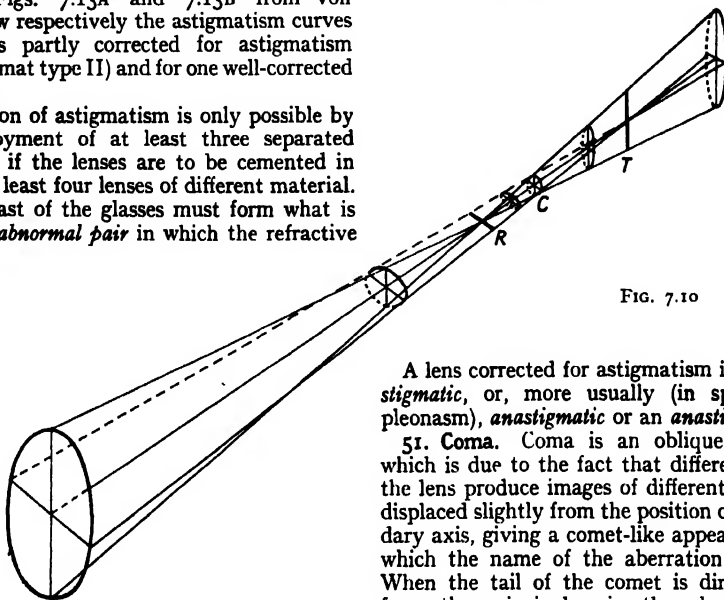


FIG. 7.10

index varies in the opposite direction to the dispersion, thus behaving in a contrary manner to the old glasses.¹



FIG. 7.11. ASTIGMATISM OF CONCENTRIC CIRCLES

It is impossible to ensure complete correction of astigmatism; all that can be done is to

¹ The first glasses to be produced which allowed of correction of astigmatism (glasses with small dispersion and high refractive index) were made experimentally in France by Fell in 1880; their manufacture was commenced in Germany towards 1890 and for a number of years gave a pronounced superiority to German optics, the legend of which still persists although with little foundation in fact.

A lens corrected for astigmatism is said to be *stigmatic*, or, more usually (in spite of the pleonasm), *anastigmatic* or an *anastigmat*.

51. Coma. Coma is an oblique aberration which is due to the fact that different zones of the lens produce images of different scale, each displaced slightly from the position of the secondary axis, giving a comet-like appearance, from which the name of the aberration is derived. When the tail of the comet is directed away from the principal axis, the phenomenon is called "outward coma." The effect of this

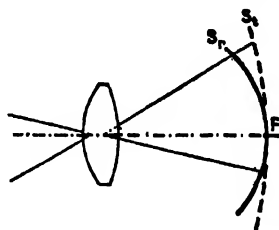


FIG. 7.12 ASTIGMATIC FOCAL PLANES

aberration, except in the case of isolated luminous-point objects (such as stars) is usually noticeable as a general reduction in the contrast of the image.

Fig. 7.14, taken from S. P. Thompson, shows the cross-section of the beam of light by a plane perpendicular to the axis in the neighbourhood of the normal position of the image of a point formed by a plano-convex lens, having a dia-

phragm like that of Fig. 7.6, but containing several annular apertures.

Coma is often associated with astigmatism, but whilst in the case of a lens incompletely corrected, astigmatism attains a maximum and then decreases as the inclination of the rays to the axis increases, coma steadily increases. Also, being of zonal origin, coma is much more

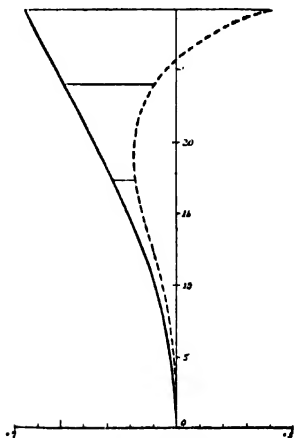


FIG. 7.13A.
ASTIGMATIC FIELDS (VON ROHR)



FIG. 7.13B.

rapidly reduced by the use of a small diaphragm than is astigmatism.

The correction of coma, particularly in high-aperture objectives, is more difficult than that of astigmatism, but it is possible to reduce it by suitable choice of curvatures and refractive indices.¹

52. Curvature of the Field. For reasons of symmetry, it is easy to see that the images of infinitely distant points given by a sphere of glass would lie on a spherical surface concentric with that of the spherical lens, and of radius equal to the focal length. In these circumstances the image of a near plane would be a surface of still greater curvature.

¹ If a biconvex lens giving minimum spherical aberration (§ 48, note) is compared with a meniscus of the same focal length with its convex surface towards the incident light, it is found that the meniscus, while giving very pronounced spherical aberration, has much less coma at an angle of incidence of 20° . A symmetrical objective is free from coma when used at unit magnification.

The focal surface of a lens of old type (achromats, rectilinears, symmetricals) always has a very marked concavity towards the lens, the mean radius of curvature being between 1.5 times and twice the focal length.¹

In an astigmatic objective the surface that is to be considered as the locus of the image is neither the radial nor the tangential surface, but an intermediate surface containing the circles of least confusion (C, Fig. 7.10).

The practical consequence of curvature of the field is that, if a plane held perpendicular to the axis is displaced relatively to the lens, the position corresponding with maximum sharpness of the central region of the image is more or less distant from that corresponding with maximum sharpness of the marginal regions of the image. In spite of the fact that (as we shall see) there is a latitude in the position of the focusing screen or photographic plate (depth of focus), in focusing the



FIG. 7.14. COMA
(S. P. Thompson)

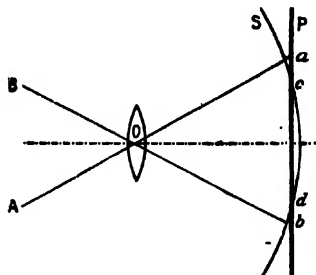
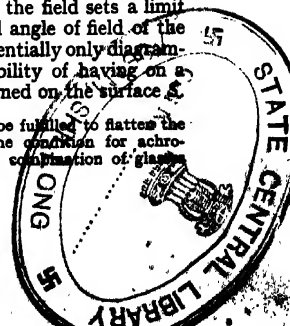


FIG. 7.15. CURVATURE OF FIELD

image sharp, curvature of the field sets a limit in every case to the useful angle of field of the lens. Fig. 7.15, which is essentially only diagrammatic, shows the impossibility of having on a plane *P* a sharp image formed on the surface *S*.

¹ The condition that must be fulfilled to flatten the field is incompatible with the condition for achromatism, unless an abnormal combination of glasses (§ 50) is used.



By adjusting the position of P to give a sharp focus for the intermediate zone cd , the central and marginal (ab) parts of the image can be considered *nearly* sharp. The useful field of the lens is then limited to the angle AOB .

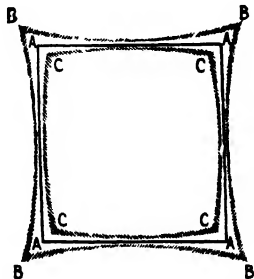


FIG. 7.16. TYPES OF DISTORTION

The curvature of the field of anastigmats is always very much less than that of ordinary objectives. In the least favourable cases the radius of curvature of the field is at least four

cushion shape $BBBB$ (Fig. 7.16) or *barrel* shaped $CCCC$, according to the position of the stop relatively to the lens. The deformation is greater the greater the angle the square subtends at the lens. Fig. 7.17 explains in a simple manner the mechanism of this phenomenon. According to the position of the stop, different portions of an oblique beam possessing aberration are used for forming the image, so that the concentration of light occurs at different distances from the axis, whilst for a pencil parallel to the axis the position of the image is independent of the position of the diaphragm. The more or less blurred images $BBBB$ and $CCCC$ result from the selection by the diaphragm of certain rays which, in its absence, would give an extremely blurred image combining these two partial images.¹

The distortion is reversed if the stop is placed behind instead of in front, from which the simple conclusion was arrived at that by placing the stop in the plane of symmetry of an objective formed of symmetrical elements the distortion would be zero. Although, in fact, distortion is reduced

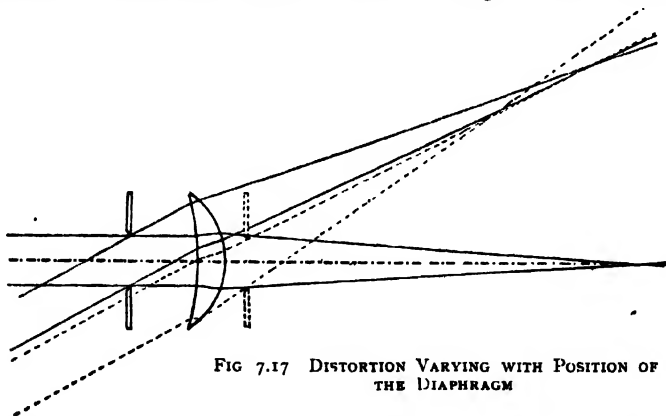


FIG. 7.17 DISTORTION VARYING WITH POSITION OF THE DIAPHRAGM

times the focal length. For astronomical work of great precision, the plates are bent into a spherical form, of curvature equal to that of the focal surface (which is very small). The glass plate, which is thin, is bent by suction against a concave support of cast iron. An earlier method of compensation was to place a plano-concave lens against the plate to lengthen the focus of the marginal parts of the image (Piazzi Smyth's corrector).

53. Distortion. It has long been known that the image of a square $AAAA$ centred on the axis by a meniscus lens will be either a *pin-*

under these conditions, it will only be zero if such an objective (said to be *rectilinear*) is used symmetrically, i.e. when producing an image of a plane surface the same size. In fact, a symmetrical lens, when used with an angular

¹ In a lens incompletely corrected for spherical aberration of oblique pencils, a displacement of the diaphragm in its own plane will produce similar deformation of the image, which will not be symmetrical if the diaphragm is not correctly centred. The same effects may arise with any aperture limiting the beam of light, e.g. the shutter, when this occupies a position other than the normal plane of the stop, or the plane of the focused image.

field of 90° in the photography of distant objects, gives quite distinct pincushion distortion.

Actually, distortion is a very general phenomenon, being present (although to only a small extent) in lenses corrected for astigmatism and curvature of the field, in which case it is due in part to spherical aberration of the nodal points, i.e. to the slight variation in the position of these points when light traverses different zones of the lens. Fig. 7.18, where the nodal point aberration is considerably exaggerated, shows that in these circumstances the images $abcd$ of equidistant points $ABCD$ cannot themselves be equidistant, the scale of the image (ratio of the object to the image) varying progressively from the centre to the edge. With pincushion distortion the scale increases from centre to edges, and the distortion is said to be *positive*; with barrel distortion (*negative*) the scale decreases from the centre to the edge.

In an unsymmetrical objective the lens designer can reduce distortion to negligible proportions for a given object distance.¹ (The name *orthoscopic* has sometimes been given to images free from distortion, but strictly speaking, an image is free from distortion only if the image of a plane object is itself a plane.) For all other object distances, distortion will be present, although it may be so small as only to be detected by laboratory methods.

Distortion, like the other aberrations, can be represented graphically. In Figs. 7.19A and 7.19B, drawn respectively for a symmetrical and an unsymmetrical lens respectively (both by the same maker, of equal excellence, and of the same aperture), the divisions of the vertical scale correspond to the angles made by the secondary axes with the principal axis, while the horizontal scale indicates percentage variation of scale, positive (+) or negative (-). Two curves are shown for each lens, one for objects at infinity

¹ It must not be inferred generally from this remark that because a lens is unsymmetrical it is necessarily free from distortion than a symmetrical lens. A badly designed unsymmetrical lens has, on the contrary, more pronounced distortion than the worst of the symmetrical lenses. Distortion also varies from lens to lens in the same series.

(∞) and the other for an object photographed at a reduction of one-tenth (from E. Wandersleb).

54. Influence of Temperature. The constants used in the calculation of objectives are usually taken for a temperature of 20°C . When an objective is used at widely different temperatures (such as in high altitude air photography)¹ the definition may be seriously affected. A reduction in temperature causes a reduction in refractive index, and a contraction of the lens elements and mounts, that is, a variation in all the quantities (indices, curvatures, thicknesses, and separations) introduced in the computation of the

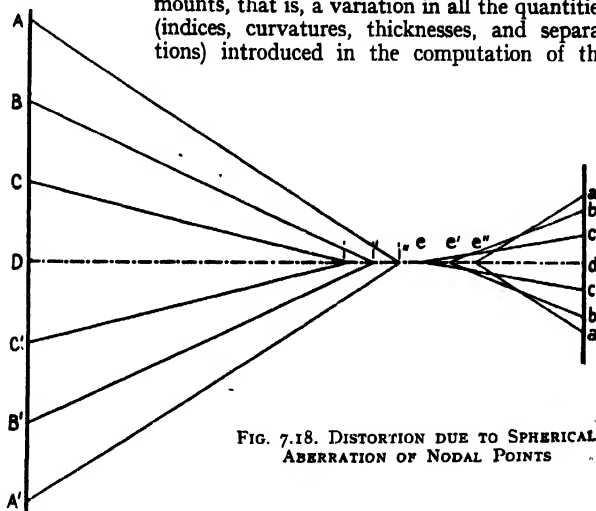


FIG. 7.18. DISTORTION DUE TO SPHERICAL ABERRATION OF NODAL POINTS

original aberrations and of focal length, the resultant of which may be in a different direction from the change in the size of the camera. The choice of suitable materials for the lens-mounts and the camera body may allow the plane of the film or plate to lie in the plane of best focus, but obviously cannot correct the aberrations introduced by reduced temperature (J. W. Perry, 1943).

With some optical glasses, the ultra-violet transmission increases at low temperatures (W. J. Arrol, 1940), which explains certain effects observed at these low temperatures.

When an objective is to be used under such circumstances, it is best to test it under similar conditions, and in particular to check the focusing scale.

It may be noted here that when an objective

¹ It was the practice in the Second World War to enclose the camera in a heated chamber, or to provide it with heated muffles.

is not in temperature equilibrium with the surrounding air (which takes some time for large-diameter objectives) the images tend to be unsharp because of local variations of refractive index of the air (E. B. Woodford and R. N. Nierenberg, 1945). At very high altitudes the variation in the refractive index of the air introduces an

appreciable change of focus in aerial cameras fitted with long-focus lenses.

55. Influence of Diaphragm Aperture on the Different Aberrations.

The employment of diaphragms with smaller apertures (up to a certain limit) improves the definition given by a lens which is incompletely corrected, but the degree of improvement is different for the different aberrations. As a rough guide (for the primary aberrations only) it may be said that chromatic aberration varies almost directly as the diameter of the stop; spherical aberration on the axis varies as a rule almost as the cube of the diameter. Astigmatism and curvature of the field are approximately proportional to the diameter and the

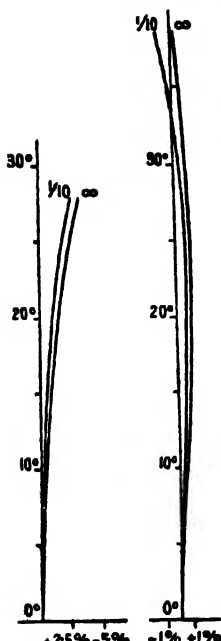


FIG. 7.19A. FIG. 7.19B.
DISTORTION OVER FIELD
OF IMAGE

square of the slope of the secondary axis to the optic axis; coma is proportional to this slope and to the square of the diameter, approximately. Distortion is independent of aperture, except when due to spherical aberration of the nodal points. These statements are true for small apertures and fields; for a given design the aberrations vary with aperture according to more complex rules.

If we consider chromatic aberration and spherical aberration, the above statements lead one to suppose that the definition on the axis will improve progressively as the aperture is reduced. It was shown in § 40, however, that the diameter of the image given by a pinhole increases as the aperture is reduced, according

to physical optics, and therefore the definition must deteriorate. This is due to the fact that when aberrations are zero, the image of a point source of light consists of a central bright spot, surrounded by concentric rings of light of lower intensity, and which become progressively weaker from ring to ring. Fig. 7.20 shows how the intensity varies along a line through the centre of this diffraction image. The central disc, which is of more importance than the rings, is called the "Airy disc," after the Astronomer Royal, G. B. Airy (1830). The phenomenon is a consequence of the wave nature of light, the study of which is called physical optics.

In view of this we would expect the size of the image of a point source, situated on the axis, to decrease as the aperture is reduced, to a point where the aberrations may be considered negligible in comparison with the diffraction



FIG. 7.20. INTENSITY
DISTRIBUTION IN DIFFRACTION
IMAGE

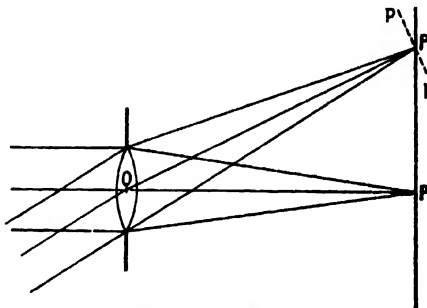


FIG. 7.21. MARGINAL INTENSITY OF IMAGE

due to the wave nature of light. From this aperture downwards the image size then begins to increase. There is thus an optimum aperture, at which the definition is a maximum.

When we consider the remainder of the field the aberrations usually increase as the slope of the secondary axis increases. Thus the aperture at which the aberrations are balanced out by diffraction effects is smaller than the corresponding aperture at which the axial definition reaches a maximum. Since the centre of the field is a geometrical point, it is of no importance in comparison with the remainder of the field, and the optimum aperture, having regard to the whole of the image area, is thus lower than the optimum aperture for the centre of the field.

A suitable measure of definition is the *resolving power*, which is the number of parallel equidistant lines per millimetre, which can be distinguished in the aerial image or in a negative made by the lens. These two resolving powers are quite different because of the difference in action between the receptors of the eye and the photographic emulsion. The resolving power also

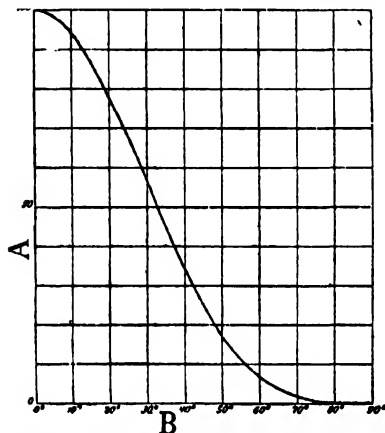


FIG. 7.22. INTENSITY OF ILLUMINATION OF IMAGE OVER FIELD OF DEFINITION

A = Illumination of image (100 at centre)
B = Angle of incidence of principal ray

has two different values for points in the field, according to whether the lines are directed towards the centre of the field, or are at right-angles to this direction.

The optimum aperture for the aerial image differs from that for the photographic image, so that over a wide range of apertures the aerial resolving power decreases with decreasing aperture, whilst the photographic resolving power increases (E. W. H. Selwyn and J. L. Tearle, 1946).

56. Distribution of Light in the Field. No objective can give a uniformly bright image of a uniformly illuminated surface, even if this is of small extent.

This can be explained by comparing the effects of a beam directed along the axis with one in an oblique direction, forming the images P and P' respectively (Fig. 7.21). Viewed from the point P the lens has the appearance of a uniformly illuminated circle, whilst viewed from P' the appearance is an ellipse, the area of which is smaller than that of the circle by an amount which increases with the obliquity. Further-

more, P' is farther from O than P , and, as is well known, the illumination diminishes when the source of light is farther away. Finally, the oblique beam illuminates the screen or sensitive surface in the plane PP' , perpendicular to the optic axis, less than it would a screen placed at pp , perpendicular to its mean direction.

Combining the effects of these different causes

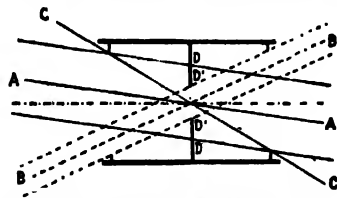


FIG. 7.23. CUT-OFF OF MARGINAL RAYS

it is possible to calculate the maximum illumination at different angles. Assuming that the Inverse Square Law is applicable, the illumination I at any angle ω to the principal axis is given by $I = I_0 \cos^4 \omega$ where I_0 is the intensity of illumination at the centre of the field. This is shown graphically in Fig. 7.22.

In practice the reduction in illumination between centre and edge of the field varies according to the construction of the lens. If the total thickness of the lens is large compared with the diameter of the lens, *vignetting* occurs.

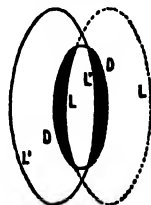


FIG. 7.24. LENS APERTURE FOR OBLIQUE PENCILS

This is illustrated in Fig. 7.23 which represents a lens mount with the lens elements removed. For a certain aperture of the diaphragm DD , all those rays more oblique than AA would be partially intercepted by the lens cell and the tube. If the diaphragm is replaced by a smaller one $D'D'$, the limit of obliquity for which there is no cutting off is increased, since, in these circumstances, the beam BB passes freely. From this it is seen that reducing the aperture of the stop reduces the variation in brightness across the field. This phenomenon can be observed by moving the eye in the plane of the

sharp image formed by the lens. It is then seen (Fig. 7.24) that the aperture of the stop DD is more and more covered by the lens rims L and L' as the eye moves away from the optic axis.

Because of these effects, the intensity of illumination at, say, 25° from the axis may be only 50 per cent of that on the axis, as against the 67 per cent given by the $\cos^4\omega$ formula.

Often the diameters of the front and rear elements of a lens are just sufficient to cover the stated aperture of the lens for the axial image only, with the result that vignetting occurs for off-axis images. This assists the lens designer, since troublesome aberrations at the higher obliquities may be reduced by this stopping

limiting inclination to the axis) is the *angle of the field illuminated*. This cone cuts the image plane in a circle.

The image, which is sharp at the centre of the circle, becomes as a rule useless at the edge as much from want of sharpness as from insufficient illumination. If we agree to accept a certain minimum standard of definition, then at a certain aperture of the diaphragm the images of distant objects will be useful within a circle, concentric with the circle of illumination, which is the *circle of good definition* under the given conditions. The vertex angle of the cone formed

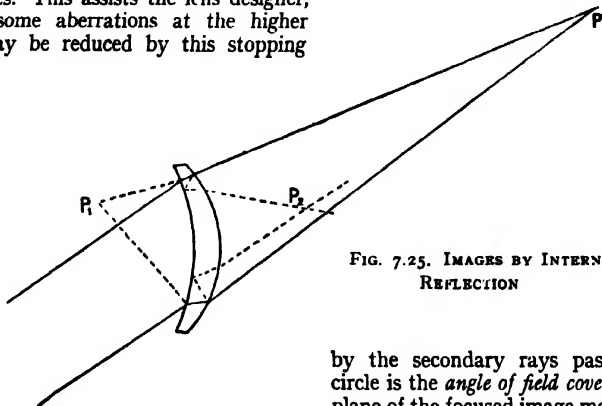


FIG. 7.25. IMAGES BY INTERNAL REFLECTION

down of the aperture. Lenses are sometimes claimed to have "extra marginal illumination" when the designer has provided sufficiently large external elements to maintain the $\cos^4\omega$ law as far as possible.

Amongst the devices used for compensating for this variation, even approximately, may be mentioned: (i) an opaque stop or a truncated cone placed at some distance in front of the lens to cut off some of the central rays; (ii) a star-shaped diaphragm, placed in front of the lens and rotated by blowing, during exposure; (iii) a graduated neutral filter placed in front of the photographic plate: this may consist of a negative of a uniformly illuminated surface taken with the same lens, or a plano-convex lens of neutral glass cemented to a plano-concave lens of clear glass to form a plane-parallel plate.

57. Field Illuminated; Field Covered. We have just seen that the image plane receives no light at an angle greater than a certain value. Rotation of the secondary axis corresponding to this angle round the optic axis generates a cone of which the vertex angle (twice this

by the secondary rays passing through this circle is the *angle of field covered sharply*. If the plane of the focused image moves away from the lens (as when the object approaches it) the angle of field sharply covered remains the same, but the circle of good definition, being the intersection of the cone with a plane farther from the vertex, increases.

The employment of a small stop to improve the definition of the oblique images and to equalize the illumination over the field often has the effect of increasing the field of view as well, but this must not be taken as a general rule. Lens catalogues indicate (or should) the *angle of field covered sharply* for each lens at different apertures, or the diameters of the circles covered, for an object at infinity. Any rectangular shape that can be inscribed in that circle will then receive a sharp image. This amounts to saying that all plate sizes of which the diagonal is less than this diameter will be sharply covered in the specified circumstances.

58. Loss of Light in Passing through a Lens. A beam of light passing through transparent matter undergoes loss, partly by absorption and partly by reflection at the entrance and emergence surfaces.

Loss by absorption within the glass of a modern lens is generally very small, often negligible, for visible rays. The mean values of transmission (not reckoning loss by reflection, to be examined later) are indicated below for different total thickness of glass, expressed in centimetres—

Thickness in cm	1	2	3	4	5	6
Transmission %	97.6	95.3	93	90.7	88.5	86.4

This loss is much greater for ultra-violet radiation, which is, however, useless and indeed often harmful in current photographic practice. The loss of light by absorption may be considerable in old lenses, certain glasses of which have a pronounced yellow coloration.

Loss by reflection at the surfaces of the lens is generally more considerable than loss by absorption. In objectives containing one or more cemented lenses the loss is negligible at the cemented surfaces (about 1 per cent); we need therefore to consider only losses at glass-air surfaces. The mean values of transmission (not reckoning loss by absorption, examined above) are given below for one, two, three, or four lenses in air, supposing that the polish is perfect.

Number of glass-air surfaces	1	2	4	6	8
Transmission %	97.6	89.7	80.4	72.1	64.6

To obtain the total transmission approximately, reckoning both causes of loss, it would be sufficient to multiply one factor by the other, e.g. a lens containing six glass-air surfaces in which the total of the thicknesses of the components is 3 cm transmits approximately.

$$72.1 \times 0.93 = 67 \text{ per cent.}$$

59. Anti-reflection Coatings. The reflectivity of glass may be reduced considerably by coating the surface with a thin film of suitable material. This phenomenon was first observed by H. D. Taylor in 1892, and was put to practical advantage by J. Strong in 1935, by depositing a film of calcium or magnesium fluoride on the lens surface in vacuum.

This reduction in reflectivity, with a corresponding increase in transmission, is an interference phenomenon. The reflectivity can be reduced to zero, for a given wavelength of radiation, and a given angle of incidence. In the case of normal incidence, the first condition is that the thickness of the film should be an odd multiple of the half-wavelength of light, the best results being obtained when a half-wavelength thickness is used. The second condition is that the refractive index of the surface film should be equal to the square root of the refractive index

of the glass on which it is deposited. This condition would appear unattainable, since no suitable substance has a refractive index lower than 1.4, whilst the required index must be 1.22 to 1.3 when the index of the glass is 1.5 to 1.7. Fortunately, in these thin films the refractive index is much lower than that of the same substance when measured in the bulk.

It is relatively easy to reduce the reflectivity to $\frac{1}{2}$ of its natural value, the transmission thus increasing for a glass of index 1.5 from 93 per cent to 98 per cent for a single element, and from

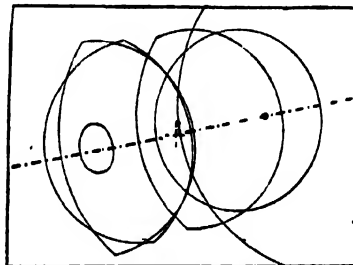


FIG. 7.26. FALSE IMAGES
(R. Schütttauf)

60 per cent to 88 per cent for a system with 6 independent elements.

In practice it is necessary to reduce the reflectivity to a minimum for green light (550 mμ), the film having a magenta appearance.

The different methods of producing anti-reflection coatings can be divided into two groups, according to whether the film is deposited on the glass (physical, or additive method) or is made by surface action on the glass (chemical, or subtractive method). Chemical methods are applicable to certain types of glass only, and are therefore not so universal. The physical methods consist either of evaporation *in vacuo* or of spinning by centrifuge. The latter is receiving attention at present, although the majority of coated lenses are prepared by Strong's method. Heating the lenses during the process leads to exceedingly hard films.

60. Effect of Internal Reflection. The light reflected at each free surface is, unfortunately, not lost; a part of the beam which has suffered several internal reflections is sent back to the object, but another part passes on to the plate. In Fig. 7.25 it is seen that the beam which forms the image *P* also gives an image *P*₁ on the side of the object, after one internal reflection, and an image *P*₂ on the side of the image *P* after two internal reflections. If the incident beam

is sufficiently intense, and if the exposure is sufficiently long, these images will be registered on the photographic plate as circular or elliptical areas of relatively large dimensions. The number of parasite (ghost) images reflected to the plate will be greater the greater the number of glass-air surfaces. The intensity of the images

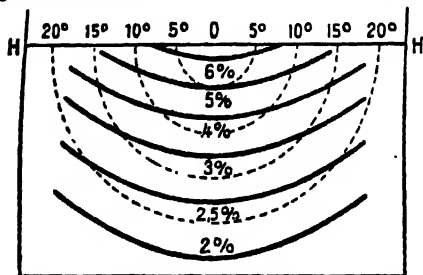


FIG. 7.27. VEIL FROM INTERNAL REFLECTION
(E. Goldberg)

diminishes according as the number of reflections the beam has undergone is greater.

Number of glass-air surfaces
Number of ghost images .

8
28

These ghost images appear frequently in photographs taken at night, which have had a long exposure and where the view contains light-sources of great intensity towards the edge of the field. Owing to the symmetry of the lens round its axis, the secondary axis of the different beams arising from the same original beam are contained in a meridian plane. The centres of the areas corresponding with a single point source are thus all situated on the straight line which joins the image of the point and the point where the optic axis cuts the sensitive surface. Fig. 7.26 (from R. Schüttauf) shows the limits of the six ghost images given by a rectilinear lens (symmetrical lens of two groups each consisting of two cemented lenses, so that there are in all four glass-air surfaces) where the object is a bright point on a black background. This phenomenon may easily be observed by placing a piece of opaque paper on the focusing screen of a camera, midway between the centre and a corner. If the camera is now directed towards the sun, so that the image of the sun falls on the opaque paper, a number of bright circles will be seen, which would have been invisible if the brighter image of the sun had remained within the field.

In some of the old lenses one of the internally reflected beams gave almost a sharp image of

the stop in the image plane, somewhat enlarged, centred on the optic axis, and superposing a bright patch (called the *central flare spot*) on the image.

In regular photographic work these ghost images are not seen individually, but the light directed towards the plate after internal reflection forms a slight fog over the whole image, reducing contrast. Fig. 7.27 (from measurements made by E. Goldberg) shows the effect of these internal reflections for an $f/6.8$ objective containing four independent lenses (eight glass-air surfaces) photographing a landscape of which HH is the horizon. Successive reflections of the light from the sky produce on that part of the plate on which the landscape is recorded an amount of light which decreases as the distance from the horizon line becomes greater. The circles in dotted lines correspond to different obliquities of the beam; the curves in full line join points of the image in which the parasite light has an intensity equal to 6 per cent, 5 per cent, . . . 2 per cent of that in the image of the sky. The intensity of this parasitical light is reduced appreciably when the lens is stopped down.

The same author has been able to establish the fact that from these reflections and from the unavoidable light scatter at the surfaces,

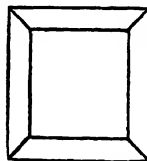


FIG. 7.28. SMALL CUBE AS
SEEN BY A LARGE LENS

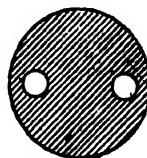


FIG. 7.29. DUPLEX
DIAPHRAGM

even if perfectly polished and kept perfectly clean, the extreme contrast in the image yielded by a lens is always less than in the subject itself examined from the same viewpoint. A subject having a range of contrasts infinitely great is reduced to a contrast about 200 : 1 with a single lens and to about 60 : 1 with an anastigmat giving a sharp image over a relatively large field. It should be noted that the stray light which produces this reduction in contrast does not represent a fraction of the light coming from the subject, but a fraction of the *total* light falling on the objective, including that which is outside the field of view. To obtain maximum contrast, a lens hood should always be used.

Goldberg's measurements confirm the experience of the old photographers, who used for landscape work a single objective consisting of a number of lenses cemented together, considering that this type gave more *brilliant* images.¹

61. Stereoscopic Effects. A lens of very large diameter, such as some at one time used as portrait lenses, gives an image of a near object in which appear certain parts of the subject which an eye (placed as close as possible to the lens) would see only if moved from right to left (Brewster, 1860) and up and down. The image of a small cube isolated in space, e.g. a dice suspended by a thread in the optic axis of such a lens, would show five faces (Fig. 7.28), presenting thus the appearance of a truncated pyramid seen from the direction of the small end.

It has long been recognized that it is possible to obtain with such a lens, fixed with respect to the object photographed, two stereoscopic images by using an eccentric stop, rotated through 180° between the exposures, the aperture being 1½ in. in a horizontal direction from the centre, so that two successive positions of the aperture are at a distance apart equal to the mean separation of the eyes. The diaphragm merely extracts from the complete image certain details by isolating certain light-rays.

It has also been proposed (Lehmann, 1878; Boissonas, 1900, etc.) to use with large lenses a diaphragm with two apertures (Fig. 7.29) to obtain a single image in which the doubling of certain outlines would suggest some idea of relief.

The painter or draughtsman, observing his model with two eyes, synthesizes the two views. It thus seems logical for the portrait photographer to use a lens of which the useful diameter is at least equal to, preferably greater than, the mean separation of the eyes (G. Cromer, 1921), without, however, falling into an exaggeration which, viewed at a short distance, would spoil the image. A lens of small diameter gives a view as seen by a one-eyed person.

In scientific photography, in which a mathematically correct perspective is required, the use of lenses of large diameter should, on the contrary, be avoided.

¹ E. Goldberg defines *brilliance* of an objective by the logarithm of the ratio I_0/I_λ where I_0 = the illumination of the image of a uniformly illuminated hemisphere centred at the optical centre of the lens, and I_λ = the illumination of a point of the image of an absolutely black object (§17) placed at the intersection of the hemisphere and the optic axis.

62. Defects of Workmanship and of Material. Photographic lenses made by reputable manufacturers are always carefully examined before leaving the workshops, and run hardly any risk of showing any faulty material or bad workmanship, but these faults are sometimes met with in lenses which carry no maker's name or bear a more or less fancy name.

Defects of material comprise non-homogeneity of the glass and imperfect annealing.

Want of homogeneity is not usually evident except in lenses of large diameter; it can be recognized by forming on a ground glass screen the image of a point source of light (e.g. the image of the sun in a well-polished metal ball or small silvered bulb) close to the axis of the lens. If now the screen is moved out of focus until a circle of light of about ½ in. diameter is obtained, any defect will be visible as striæ or dark zones.

Bad annealing, which gives rise to *double refraction* of the rays of light (leading to a doubling of the image) can only be seen by examination in polarized light in an optical laboratory provided with the proper equipment.¹

Excessive pressure on the glass in its mount may also lead to double refraction.

Beginners have a tendency to consider the *bubbles* seen in *every* anastigmat as a defect. These bubbles, enclosed in the glass in the course of the second melting (after the first melting has been broken up and faulty pieces rejected) cannot be removed except by completely liquefying the glass, which would have the effect of separating the constituents in the order of their density and thus cause a defect much more serious than the bubbles, of which the sole effect is to diffuse about one-thousandth part of the light—an absolutely negligible amount.

One fault most frequently met in commercial objectives is bad centring, due largely to incorrect alignment of mounts. In bad cases this can be detected by looking at the images of a point source of light reflected in the lens surfaces; these should lie exactly on a straight line.

There is a regrettable tendency amongst some camera manufacturers to buy lens elements in individual mounts, which are then screwed into between-lens shutters. Unless careful optical control is maintained the standard of performance of such lenses is certain to be unreliable.

¹ If the lens is placed between crossed polarizing filters (§122) these faults will show as alternate light and dark areas.

CHAPTER VIII

FOCAL LENGTH OF LENSES: IMAGE SCALE: CONJUGATE POINTS

63. Conjugate Points. When a point R' is the image of a point R (Fig. 8.1) formed by an optical system, the point R is also the image of R' (principle of *reversibility* of light rays¹); the points of such a pair are two *conjugate points* of the optical system considered. Various formulae and simple graphical constructions enable us, when the focal length of a lens and the positions of the nodal points or foci (§§ 45 and 46) are

negative vergence of the beam ($-1/u$), the emergent beam will have vergence $1/v$ where

$$1/v = \frac{1}{f} - 1/u$$

$$\text{or } 1/v + 1/u = 1/f$$

If, instead of considering distances from the nodal points, we measure our distances from the

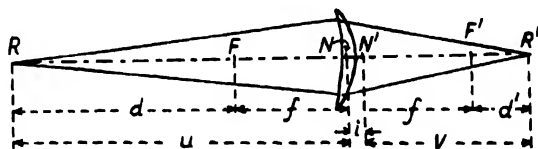


FIG. 8.1. IMAGE FORMATION

known, to determine the position of the image of a point the position of which is known.

In the theoretical discussion which follows we assume that the lens does not suffer from aberrations. Except when otherwise stated, all distances are measured from the appropriate nodal point.

The *power* of a lens (*convergent power* or *vergence*) is the reciprocal, $1/f$, of the focal length; when the focal length is measured in metres the power of the system is expressed in *diopeters*. Thus, for example, a lens of 0.20 m (8 in.) focal length has a power of $1/0.20$, or 5 diopeters.

The effect of an optical system is to add its convergence (or subtract, in the case of a divergent system, i.e. of negative *vergence*) to that of the light beams passing through it. A point at distance u from the front nodal point sends to the system a divergent beam of which the vergence is $-1/u$. If the convergence (positive vergence) $1/f$ of the system is greater than the

front and back focal points (i.e. by replacing u and v by $d + f$ and $d' + f$ respectively), we obtain the law of conjugate points in the convenient form given by Newton—

$$d \times d' = f^2$$

Expressed in words, this means that the distance from the object to the front focal point, multiplied by the distance from the image to the back focal point, is equal to the square of the focal length.

Among the different methods of graphically representing the law of conjugate points, the following (Lissajous, 1870) enables us to account for all the practical consequences of this relationship at first sight. Construct a square (Fig. 8.2) $NFMF'$, of which the sides are equal to the focal length of the lens considered, and produce the sides NF and NF' to X and Y respectively. From the origin N mark off NR on NX equal to the distance (u) of the point object (FR is thus the extra focal distance d); join RM and produce it to meet NY in R' . The length NR' is equal to the distance v of the point-image and $F'R'$ is the focal distance d' . If now RR' is rotated about M , its intersections (produced if necessary) with NX , NY correspond to two conjugate points.¹ It is seen that as R

¹ The principle of reversibility is frequently misinterpreted. For instance, if a number of points at different distances from the lens have been photographed on a flat plate it cannot be expected that by a reversal process the images of the photographed points will coincide with the system of points photographed. Again, an image defaced by aberrations (distortion excepted) will not, by a system of reversal, form a sharp image. Even a sharp photograph cannot, by reversal, yield an image as sharp as the original, since the aberrations in each process add up.

¹ This property can be verified by consideration of the similarity of the triangles MFR , $R'F'M$ or by equating the area of the triangle RNR' to the sum of the areas of the square and the two triangles MFR and $R'F'M$.

moves away from the lens, R' moves nearer to it, and vice versa. When R moves to infinity, the straight line MR becomes parallel to NX , and R' coincides with F' . Inversely, if R approaches F , the straight line RM becomes parallel to NY and consequently R' recedes to infinity.

64. Relations between the Size of Object and Image. If we consider a lens without appreciable distortion or curvature of the field (which would obviously not be the case with the meniscus represented in Fig. 8.3), we know that the images of all points on a plane perpendicular to the

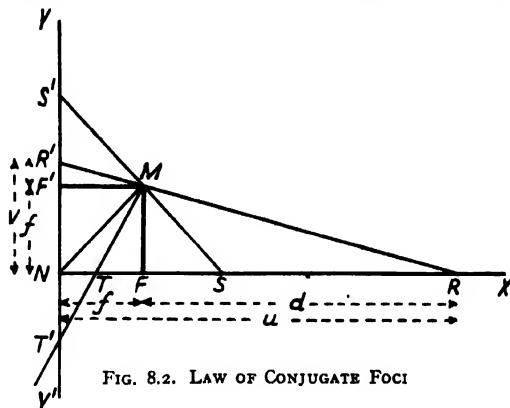


FIG. 8.2. LAW OF CONJUGATE FOCI

If the point R approaches closer to the lens than the focal length, e.g. to the position marked T , the straight line MT no longer meets NY , but its prolongation NY' , in T' , corresponding to a virtual image (§ 44).

A particularly interesting case is that in which the distance from the object S to the nodal

optic axis lie on another plane also perpendicular to the optic axis. Knowing also that the exterior parts of a secondary axis are parallel straight lines (lines joining object and image points to the corresponding nodal points), we can determine the *scale of the image* (relation between corresponding dimensions of object and

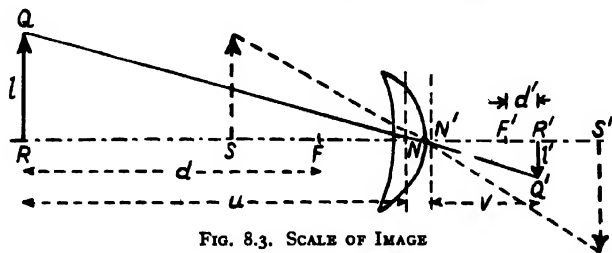


FIG. 8.3. SCALE OF IMAGE

point is twice the focal length. In this case $FS = MF$, and the straight line MS is inclined at 45° , and S' is such that $NS' = NS$. The two points S and S' at equal distances from their respective nodal points are called the *symmetrical points* of the lens; their separation is the shortest distance that can exist between a point object and its real image. Another particular case, but of no practical interest, is that where the points R' and R'' coincide with N ; this leads to the fact already mentioned (§ 45) that the nodal points are conjugate.

image) of an object of which the position is known relatively to a lens of known focal length.

Let us suppose that the length of the image of an arrow RQ (Fig. 8.3) of length l perpendicular to the axis, at a distance v , is to be determined. Join by a straight line the point Q to the front nodal point N , and draw through the back nodal point N' a line parallel to QN to meet in Q' the straight line $R'Q'$ through R' (the image of R), parallel to RQ . The point Q' is the image of Q , and the element of line $R'Q'$ is the image of QQ . The length l' of this image

can be ascertained from l , since the triangles RQN and $R'Q'N'$ are similar.

The scale of reproduction m is then equal to the ratio of the ultra-nodal distances of image and object

$$m = l'/l = v/u$$

By replacing u by v/m in the expression $1/u + 1/v = 1/f$, we find that

$$u = (1 + 1/m)f$$

$$\text{and } v = (1 + m)f$$

It is often useful to know the distance between object and image in terms of the magnification and focal length.

This is given as

$$u + v \pm i = (m + 1)^2 f$$

where i is the inter-nodal distance, which can usually be neglected.

Another expression relating object and image is the distance x' which the lens (or focusing screen) must be moved from the infinity position when the object is moved from infinity to a finite distance u . This is

$$x' = f^2/(u - f)$$

There is a reduction whenever the object is farther from the lens than its image, and magnification whenever the object is closer to

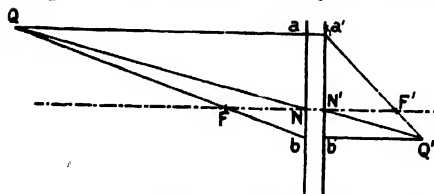


FIG. 8.4. GEOMETRY OF IMAGE FORMATION

the lens than to its image. The scale is zero when the object is at an infinitely great distance (e.g. the stars). The distance between the images of two distant objects cannot be determined from considerations of scale. It is determined from the angle seen to subtend the two point objects, e.g. the solar disc is viewed from the earth under an angle of 32 minutes of arc (*apparent diameter*) i.e. about $1/100$ th of this distance. The image of the sun will thus be equal to $1/100$ th of the focal length of the lens used. The mean diameter of the lunar image is about the same size as that of the sun.

When the object photographed has a certain depth, it is no longer possible to speak of the

scale of the image, since this will vary from point to point. It should be mentioned here that in the most general case, where such an image is photographed on a plane perpendicular to the axis, the relative dimensions of the different parts of the image are inversely proportional to the ultra-nodal distances of the corresponding point objects, and not to their ultra-focal distances, the point images being all on the same

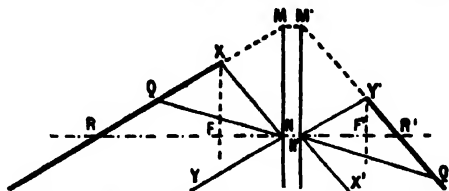


FIG. 8.5. IMAGE FORMATION ON INCLINED SURFACE

plane and no longer the *conjugates* of the point objects.

65. Graphical Construction of the Image Formed by an Optical System. Knowing the position of a point object Q relatively to the foci F and F' , and the nodal points N and N' of an optical system, the position of the image Q' can be determined as follows: Draw the optic axis FF' (Fig. 8.4), and at N and N' draw perpendiculars to it to indicate the nodal planes. From Q draw a straight line parallel to the axis, meeting the nodal plane of emergence in the point a' ; a' is the image of a , the intersection of the ray with the front nodal plane. The emergent ray will then pass through the focus F' , since all incident rays parallel to the axis, after refraction, meet the optic axis at the back focus. Draw another line QF and produce it to meet the front nodal plane in b ; the image of b is b' on a line through b parallel to the axis, which is also the emergent ray. Q' , the intersection of $a'F'$ and bb' , is the image required. The accuracy of the construction can be tested by seeing whether QN , $Q'N'$ of the secondary axis are parallel to one another.

66. Image of a Plane Inclined to the Axis. Consider a lens of which the foci and nodal points are F, F' and N, N' respectively (Fig. 8.5), and let R and R' be two conjugate points. If a plane perpendicular to the plane of the paper meets the optic axis obliquely at R , all the points in this plane (at least all those not far from the axis) form their images on another plane, also meeting the optic axis obliquely at R' and perpendicular to the plane of the paper.

This image plane is defined by the condition that its intersection M' with the back nodal plane should be the image of the intersection M of the object plane with the front nodal plane.

It is easily seen that the image is deformed relatively to the object. In particular the points on the line X , the intersection of the object plane with the front focal plane, will be imaged at infinity, the secondary axes NX , $N'X'$ being parallel. In the same way infinitely distant points of the object plane in the direction NY will be imaged on the straight line Y' , the intersection of the image plane with the back focal plane. On this straight line all the vanishing points of parallel straight lines in the object plane will be imaged, while all lines meeting in X will be parallels in the image plane.

This manner of distorting is made use of for correcting the perspective of photographs accidentally taken on an inclined plane (by making all the vanishing points of vertical lines in such a perspective meet in X , they will be corrected in the image), or for making lantern slides which are to be projected obliquely. We shall return to this subject in more detail in Chapter XLVIII.

67. Experimental Determination of the Focal Length of a Lens. The method of measuring the focal length usually described consists in focusing a distant object (distant at least 1,000 times the focal length to be measured) in the camera, then focusing an equal size image of an easily measurable geometrical figure (e.g. a circle or equilateral triangle). The amount the camera has to be extended between the two positions is exactly the focal length.

If it is not possible to extend the camera front sufficiently to obtain an equal-size image, it is sufficient to obtain a second position at a reduction of m . The distance through which the focusing screen is moved is thus $v - f$. Since $v = (m + 1)f$, it follows that $f = \frac{v - f}{m}$. It should be noted that m should be as large as possible, to avoid errors in measurement.

Instead of focusing on a distant object, two finite object distances can be used. The method is to focus a scale at two different magnifications, m_1 and m_2 , and to measure the difference $v_2 - v_1$ between the two image distances. Then, since $v = (m + 1)f$, we have

$$v_1 = (m_1 + 1)f$$

$$v_2 = (m_2 + 1)f$$

$$\text{whence } f = \frac{v_2 - v_1}{m_2 - m_1}$$

In other words, the focal length is the difference in extension measured, divided by the difference between the two scales of reproduction.

If, for example, the test object is an equilateral triangle of which the sides are 4.8 in. long, reduced in the two positions to 3.6 and 1.6 in. (scales of reduction 0.75 and 0.33 respectively) and that the increase in camera extension is 2.8 in., the focal length will be given by

$$2.8/0.42 = 6.67 \text{ in.}$$

The position of the back focus could be easily found by measuring the ultra-focal distance nf from one of the positions of the image towards the lens. The position of the back nodal would be given by measuring a further distance f towards the lens.

In both of these methods care should be taken to ensure parallelism between object plane and focusing screen, and it is convenient to reverse the focusing screen so that the images can be measured directly on the ground glass side.

Where the only camera available is capable of only a small range of focus (which is the case with a large number of hand cameras) the above method is not possible, and the following method can be used based on the formula

$$u + v \pm i = \frac{(m + 1)^2 f}{m}$$

given in § 64 (Debenham, 1879). Having focused the image of a geometrical figure and determined the scale m , the total distance l between object and image is measured. This distance is the sum of the two ultra-nodal distances u and v increased or diminished by the nodal interval i (separation of the nodal points) according as the nodal points are in the normal position or crossed (the *nodal points* are said to be *crossed* when the back nodal point is the nearer to the front focus, which is opposite to the case of the systems previously considered).

If m is very small (which will always be the case in small cameras) $1/m$ will be very large, and consequently the error arising from neglecting the internodal distance will be divided by a number generally greater than 10 and will therefore nearly always be negligible, except in telephoto and single lenses of convertible sets. If, for example, a lens of 6 in. focal length has an internodal distance of 0.12 in., if the scale of reduction is $1/10$, and the total separation between object and image is 71.5 in., the formula gives a focal length of 5.9 in., which is

sufficient approximation for all practical purposes.

A variation of this method will avoid the error arising from neglecting the internodal distance, whatever its value, and at the same time determine it. Having measured the total distances l and l' for two scales m and m' , the

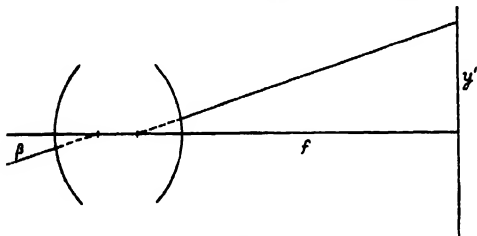


FIG. 8.6. COLLIMATOR METHOD OF DETERMINING FOCAL LENGTH

focal length F and internodal distance i are given by

$$F = \frac{l - l'}{\left(m + \frac{1}{m}\right) - \left(m' + \frac{1}{m'}\right)}$$

$$i = l - \left(2 + m + \frac{1}{m}\right)F$$

respectively.

If, for example, it has been found that

$$\text{for } m = 1/5 \quad l = 43.6 \text{ in.}$$

$$m' = 1/3 \quad l' = 32.4 \text{ in.}$$

it follows that

$$F = \frac{11.2}{1.866} = 6.0 \text{ in.}$$

$$\text{and } i = 43.6 - 6(2 + 5 + 1/5) \\ = 43.6 - 43.2 = 0.4 \text{ in.}$$

These methods of measurement of focal length presuppose that the lens is free from distortion. That is to say, if a ray is directed towards the front nodal point so as to make an angle β with the principal axis (Fig. 8.6) it will strike the focal plane at a distance y' from the principal axis such that $y' = f \tan \beta$. The equivalent focal length can be measured in the laboratory, using a single collimator whose direction can be changed, or a number of collimators placed at fixed angles to the principal axis. The values of y' can then be found, and the equivalent focal length is defined as the limiting value of $y'/\tan \beta$ as β approaches zero.

The British Standards Institution recommend

that the equivalent focal length so measured should be within ± 4 per cent of the value marked on the lens.

For accurate photogrammetric work it is necessary to know the *calibrated focal length*. If the lens suffers from distortion, however slightly, the distance of the image from the principal axis will be greater or less than the value given by the $y' = f \tan \beta$ formula. That is,

$$y' = f \tan \beta + \Delta y'$$

where $\Delta y'$ is a measure of the distortion. To measure the calibrated focal length it is necessary to carry out the laboratory method described above for the equivalent focal length, and then find a value of f which will give equal maximum and minimum values of $\Delta y'$. For this type of work the British Standards Institution recommend that the value of the calibrated focal length should be within ± 0.1 per cent of the value marked on the lens.

68. Direct Determination of the Position of the Nodal Points and the Focal Length. If the lens is rotated about an axis perpendicular to the optic axis, and containing the back nodal point, the images of very distant points remain fixed during the rotation, at least if it is not large and if the angle between the secondary axis to the point object and the optic axis is never very great (Moëssard, 1889).

To explain this, consider a lens (Fig. 8.7) which, for the sake of simplicity, we suppose to be reduced to the nodal planes N_1N_2 . The image of an infinitely distant object in the direction N_1M on the axis is formed at the focus F . After rotation about an axis perpendicular to the optic axis through the nodal point of emergence N_2 , the nodal point of incidence will move to N_1' . The point object being infinitely distant, the secondary axis $N_1'M'$ to this point is parallel to N_1M . By virtue of the definition of the nodal points (§ 45) the two exterior parts of the secondary axis are parallel to one another; the secondary axis thus emerges from the lens in the direction N_2F .

This property, which is made use of in the greater number of panoramic cameras, can also be utilized to determine the position of the nodal points and the focal length directly. The lens being mounted so that it can be moved to and fro on a platform which can rotate about a vertical pivot, the image is formed on a fixed screen and observed while the lens is moved on the platform until a position is found such that the images of distant points remain stationary

while the lens is rotated. The nodal point is then on the axis of rotation and the distance of this axis from the screen is the focal length required (Moëssard Tourniquet, 1893). Turning the lens end for end, the other nodal point can be found similarly, and a second measurement

We shall suppose, in what follows, that the nodal points coincide with the optical centre. If this is not accurately true, it will be necessary to assign to one of the nodal points the position indicated by the centre, and move the conjugate point corresponding to the other nodal point

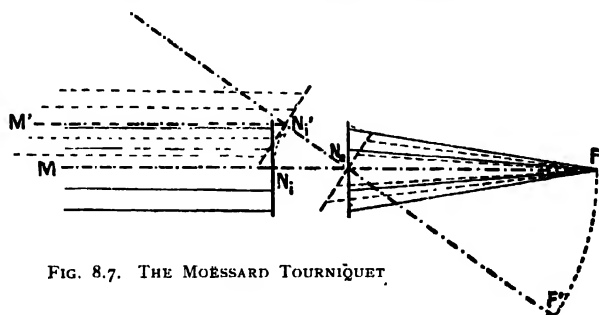


FIG. 8.7. THE MOËSSARD TOURNIQUET.

made of the focal length, which gives a useful check on the first measurement.

The displacements of the image noticed when the angle of rotation is large enable us to determine the form of the focal surface point by point, and to study the various aberrations of the image.

69. Automatic Adjustment of Object and Image. The relations between the ultra-focal

in an appropriate direction by an amount equal to the nodal interval.

1. Consider (Fig. 8.8) two points O and I , free to move in a slot parallel to the optical axis. At C , the intersection of the slot with the plane drawn through the optical centre at right angles to the optic axis, erect a perpendicular CD , of length equal to the focal length f . By making a bent lever, pivoted at D and having slots of which

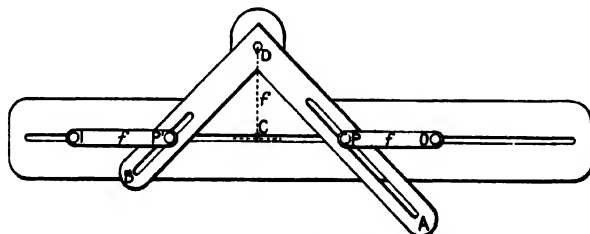


FIG. 8.8. SELF-FOCUSING LINKAGE (Carpentier)

distances of two conjugate points, or of planes perpendicular to the axis passing through them, can be translated geometrically so that automatic linkages between these planes can be made, so dispensing with all focusing in enlarging or reproduction. The only adjustment to be made is that for the scale of reduction, obtained by the displacement of one of the conjugate planes, the image remaining sharp throughout. Numerous solutions of this problem have been given; we shall indicate only some of them, selected from the most characteristic.

the axes meet at right angles in D (J. Carpentier, 1898), rotate, it is possible to constrain two studs P and P' in the axial slot to move so that their distances d and d' from the point C will always satisfy the relationship between the ultra-focal distances of two points, viz.

$$dd' = f^2$$

This is possible since in the right-angled triangle $P'OP$, in which a perpendicular is dropped from the right-angle D to the hypotenuse PP' , $P'C \times CP = (DC)^2 = f^2$.

It will then only be necessary to join P and

P' to O and I respectively by two connecting rods, of length equal to f , to make certain that O and I are conjugate points, and consequently also the two planes perpendicular to the axis through them.

2. Another linkage (G. Koenigs, 1900) is formed of an articulated lozenge $P'AP''B$ (Fig. 8.8) and two equal rods AC, CB , pivoted at their joint. If we represent by m the common length of the four sides of the lozenge and by n that of the connecting rods, the lengths $d = CP'$ and

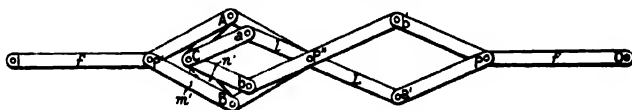


FIG. 8.9. SELF-FOCUSING LINKAGE
(Koenigs)

$d' = CP''$ (which, by reason of symmetry, are obviously in a straight line)¹ will always be such that

$$dd' = m^2 - n^2$$

We then only need to give to the constant value of this product the square of the focal length in order to get the required linkage, but in these circumstances the jointed lozenge would generally be of very great dimensions; by mag-

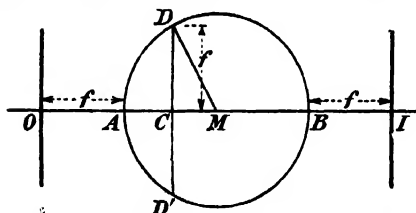


FIG. 8.10. PRINCIPLE OF FOCUSING LINKAGE.

nifying the movements transmitted from P'' to P by means of a pantograph $CaP''a'Pb'P''bC$, the size will be considerably reduced. If the two coupled lozenges of the pantograph have sides of length l and L respectively, it will only be necessary to satisfy the relationship

$$m^2 - n^2 = f^2 \frac{l}{L + l}$$

3. Let (Fig. 8.10) the points O, I on the optic axis of the lens C be the intersections of the

¹ A circle with A as centre and radius m will pass through the points P' and P'' . Now the product of the distances of any point C from the two intersections of the circle by a chord through C , i.e. the product $CP' \times CP''$, is equal to the difference between the squares of the radius m and the distance n of the point C from the centre of the circle.

copyholder and plateholder. From these points draw towards the lens, distances equal to the focal length f . The points A and B thus obtained must be at distances from C such that $CA \cdot CB = f^2$. Using AB as a diameter draw a circle with a centre M and through C draw the chord DD' perpendicular to AB . Elementary geometry teaches that $CA \cdot CB = CD \cdot CD'$, hence $CD = f$. The rays MA, MB, MD are evidently equal and, conversely, by this last equation the respective distances of the conjugate points $OC,$

IC can be definitely determined (P. R. Burchall, 1933). Among the methods of linking based on this principle may be mentioned (A. Bonnetain, 1934) a system of three racks engaging in M on one and the same toothed wheel.

4. Finally, there are numerous arrangements based more or less directly on the hyperbolic cam¹ (G. Pizzighelli, 1889). For instance, a table T on which the optical centre C is fixed

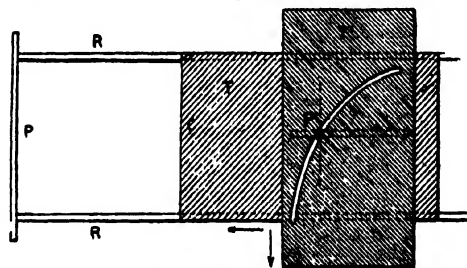


FIG. 8.11. SELF-FOCUSING CAM
(Pizzighelli)

can slide on two rails RR (Fig. 8.11) perpendicular to the object plane P . Movement of the table T is communicated by means of racks and pinions to a table T' , but in a direction at right angles. A slot in T' in the form of a rectangular hyperbola acts on a stud P' which is constrained to move in an axial slot in T . Any plane perpendicular to the optic axis and containing P' will be conjugate to P .

An obstacle to the employment of these devices in practice is the difficulty of obtaining

¹ The relation $dd' = f^2$ is the equation of a rectangular hyperbola with the asymptotes as axes. The vertex is at a distance f from the two asymptotes.

delivery of a series of lenses of exactly equal focal length, so that it is impossible to make this equipment in quantity. A number of linkage arrangements have been brought out in the last few years which have an adjustment for compensating for slight variations in the focal length.

70. Combination of Lenses or Optical Systems. It sometimes happens that another system, convergent or divergent, has to be added to a lens, and it is desirable to be able to determine the focal length of the combination, the optic axes of the different components being assumed to coincide (centred system).

For thin lenses in contact the law that *the power (§ 63) of the system is the sum of the powers of the components* may be considered exact, it being understood that negative powers (corresponding with divergent lenses) are to be subtracted.

Calling f and f' the focal lengths of the components and F that of the resultant system, then

$$1/F = 1/f + 1/f'$$

In general, however, this rule is not applicable, and account must be taken of the *spacing of the combination*, i.e. the separation between the back nodal point of the first system and the front nodal point of the second.

Referring the reader to a treatise on optics for the proof, we shall limit ourselves to formulating the rule. Calling e the separation as defined above, the resultant focal length is given by

$$1/F = 1/f + 1/f' - e/ff'$$

The resultant focus is at a distance D from

the back focus of the second system, equal to

$$D = \frac{f'^2}{e - (f - f')}$$

The focal length of the combination can be found by considering the separation δ between the back focus of the first system and the front focus of the second. The interval δ is connected with the interval e by the relation

$$\delta = e - (f - f')$$

from which it may be shown that the resultant focal length is

$$F = ff'/\delta$$

These rudiments will have an application to the case of lenses in which focusing is effected by varying the separation of their components (§ 110), to supplementary lenses (convergent or divergent, § 117) and to telephoto lenses (§§ 107 and 108).

To determine the focal length of a divergent lens the procedure is the same as for a convergent lens but a *virtual object* must be used, which can be the image of an object formed by a convergent system of relatively great focal length, the divergent lens being placed between the convergent system and the real image.

For an approximate value of the focal length, the lens may be directed towards the sun, and the distance from the lens to a screen measured when the diameter of the circle of light on it is double that of a circular aperture placed against the lens; or a thin divergent lens may be neutralized by placing it in contact with a thin convergent lens of the same focal length (the method used by oculists).

CHAPTER IX

DIAPHRAGMS AND RELATIVE APERTURE : EFFECT ON PERSPECTIVE AND INTENSITY

71. Relative Aperture of a Diaphragm. The diameter of the beam of rays incident parallel to the axis which, after refraction through the lens components in front of the diaphragm, completely fills the latter is called the *effective diameter* of the diaphragm. Thus, D , D' and D'' (Fig. 9.1), although of different diameters, all have the same effective diameter d .

If, without altering the position of the stop, the real diameter is altered, its effective aperture varies proportionally. The constant ratio between the effective and the real aperture is

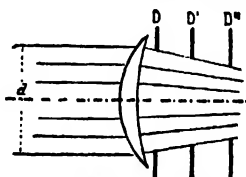


FIG. 9.1 EFFECTIVE APERTURE

sometimes called the *coefficient of the effective aperture*, and is equal to 1 only if the beam of light reaches the stop before meeting the lens (the case with some single lenses). In the general case, in which the stop has in front of it one or more lenses forming a convergent system, the coefficient is greater than 1. As the value depends on the construction of a given lens, obviously no rule can be given, but it may be stated that with symmetrical anastigmats it generally lies between 1.1 and 1.15, whilst with anastigmats consisting of three separated lenses it often amounts to 1.3.

If the diameter of the effective aperture is x/n th the focal length f , the aperture is said to be f/n , which is also called the *relative aperture* of the diaphragm considered. If, for example, the real diameter is 0.8 in. and the effective aperture is 0.92 in. of a lens of 4.6 in. focal length, the relative aperture is $f/5$. This is often designated as the *f-number*.

The relative aperture of the largest stop a lens can use is called the *maximum relative aperture*, or, more simply, the *maximum aperture* of the lens. We shall see later (§ 89) that the *maximum relative aperture* of a lens is the principal factor governing its speed. It was seen in § 56 that the illumination in the focal

plane is reduced as the angular separation from the axis is increased, so this statement is true for the centre of the field only.

72. Different Types of Diaphragms. In order to be able to get all possible apertures with a lens, modern objectives are usually fitted with an *iris diaphragm* (Fig. 9.2) having an aperture which can be varied by means of a rotating ring or external lever on the mount. In Fig. 9.2 the guiding slots of the movable ring are shown radial, which is the usual form. By sloping them it is possible to make the usual markings of apertures almost equidistant (Lan Davis, 1911). The thin blades of the iris are of ordinary steel or ebonite. Though ebonite has the advantage of not rusting like steel, in damp climates, care must be taken not to subject it to great heat. Hence an ebonite iris should not be used in an enlarger or projector using a condenser, or there will be danger of the blades melting or burning.

With lenses of which the component glasses are too closely spaced to accommodate an iris, a *rotating diaphragm* is employed (Fig. 9.3). Here an eccentric disc has a number of different apertures, which, by rotation of the disc, are brought into position concentric with the axis of the lens. The size of the aperture in position is indicated by a number engraved on the part of the projecting disc opposite the aperture.

In many old lenses and in modern lenses for process work, *Waterhouse stops* (Fig. 9.4) are inserted through a slot in the side of the lens tube. The making of negatives through screens, as used in preparing half-tone blocks or in lithography, requires stops with non-circular openings (generally square), and capable of being variously orientated in the lens tube.

73. Pupils of an Optical System. The beams of light passing through an optical system are limited by the aperture of the diaphragm. Now the components of the system in front of the stop (lens L_1 , Fig. 9.5) form a virtual image (called the *entrance pupil*, P_1) of the stop D . The entrance pupil is such that the prolongation of rays through L_1 , which afterwards are just bounded by the diaphragm D , reach the outline of the entrance pupil. The diameter of the entrance pupil is the effective aperture of the diaphragm just mentioned.

In like manner the components behind the diaphragm (L_2 in Fig. 9.5) form a virtual image of its aperture, called the *exit pupil* P_e , the outline of which is reached by the prolongations of those rays which (before passing through L_2) just reached the outline of the diaphragm D (E. Abbe, 1890). The two pupils¹ are thus conjugate with respect to the complete lens.

formation of the image, without upsetting in any way the conclusions that have been drawn, as to the position and dimensions of this image, from the positions of the nodal points and the foci.

74. **Photographic Perspective.** The photographic image is an exact perspective rendering of the objects represented, the viewpoint of

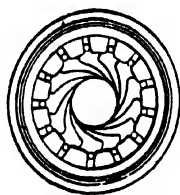


FIG. 9.2. IRIS DIAPHRAGM

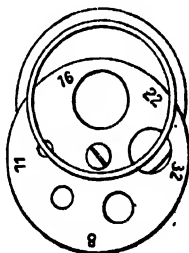


FIG. 9.3. ROTATING DIAPHRAGMS

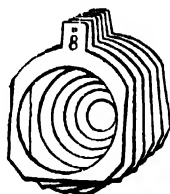


FIG. 9.4. WATERHOUSE DIAPHRAGMS

If we suppose the diaphragm aperture gradually reduced to a small opening O on the axis, admitting but a single ray of light, this single ray would be the one originally directed to the point I , the centre of the entrance pupil, and would appear to emerge, after passing through the lens, from the point E , the centre of the exit pupil. The ray RR' forms what is sometimes called a *principal ray*.

In the particular case where the stop is placed with its centre at the optical centre of the instrument (which frequently happens with symmetrical lenses), the centres of the pupils coincide with the nodal points, but this coincidence does not occur with single lenses, convertible sets, nor telephotos, and in other types of lenses is not always aimed at.

Just as by consideration of nodal and focal points it is possible to determine the dimensions of the image without considering the construction of the optical system forming it, so by consideration of the pupils it is possible to determine the perspective and the centre of projection of images without having to be concerned with the optical system. The pupils in fact determine which of the rays are used in the

which, relatively to the objects, is the centre of the entrance pupil; relatively to the image, the viewpoint is usually identical with the nodal point of emergence.

Consider (Fig. 9.6) the two conjugate planes QQ' of an optical system represented by its nodal points, foci, and pupils, and let us find how the points R and S outside the plane Q will

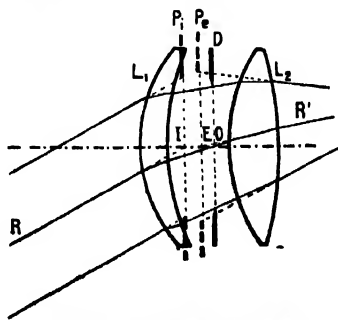


FIG. 9.5. PUPILS OF A LENS

be reproduced on the plane Q' , R' and S' being the respective images of R and S (the graphical construction is indicated by dotted lines) and being themselves outside Q' .

The bundle of rays used in the formation of the image of the point R is limited by the cone with apex R and base P_1 (the entrance pupil). After passing through the lens it forms another cone, having the exit pupil P_2 as base and R' as

¹ The pupils must not be confused with the windows (German, *Lüke*), consideration of which is less frequent in treating of photographic lenses. The windows are the images formed by the two systems L_1 and L_2 of the aperture limiting the field of view (the mount of the lens or the aperture of some attachment to the lens), and thus correspond with the field stops in observational instruments.

apex. These two cones form circular patches (*circles of confusion*) on the *focused plane* Q and on its conjugate Q' , where the focusing screen or photographic plate is placed. The circles of confusion are conjugate, with their centres r and r' at the intersections of the principal ray with the respective planes, and the ratio of their sizes is equal to the ratio of the distances of Q and Q' (say m). If the patch at r' is sufficiently small and the photograph is viewed at a sufficiently large distance, the patch is indistinguishable from the geometrical point

75. The fact that the construction of the lens (except in the case of very pronounced distortion) and its focal length have no influence on the perspective of the image can be proved by photographing an architectural subject *from the same viewpoint* successively with a pinhole (§ 40) and with lenses of very different focal lengths. The different images thus obtained will be identical except for size.

It is thus incorrect to attribute to the use of a short-focus lens the unpleasant, almost distorted, views which are easily obtained with these lenses.

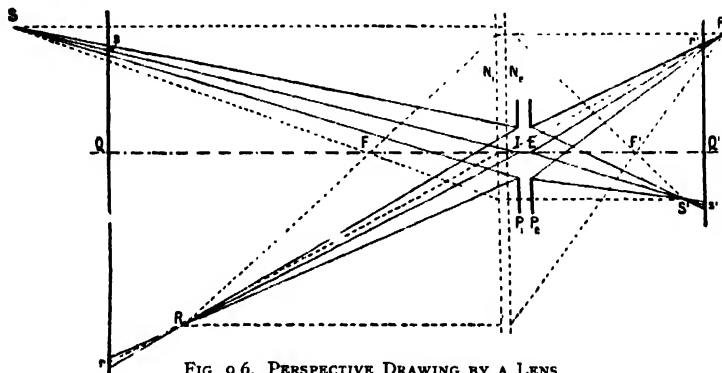


FIG. 96. PERSPECTIVE DRAWING BY A LENS

image of r (the secondary axis corresponding to r has been drawn in Fig. 9.6).

The photographic image thus coincides with a photograph, made on a scale of reproduction m , of the perspective of the objects projected on the plane Q from a point coinciding with the centre of the entrance pupil. It is thus itself a perspective view if the lens is free from distortion and the diameter of the entrance pupil is a small fraction of the distance of the objects represented, so that stereoscopic effects are avoided (§ 61).

Now it is known that different perspectives obtained by proportional enlargement or reduction have their principal distances proportional to their respective scales (§ 27). The principal distance of the perspective at Q' (the photographic image) is thus the product of the distance of Q from the entrance pupil, multiplied by m .

When the object distance is large compared with the distance between the entrance pupil and the front nodal point, the principal distance of the photograph can be taken as the image distance, and the viewpoint as the back nodal point (L. P. Clerc, 1923).

These perspectives, exact but unpleasant, are due solely to the choice of too close a viewpoint. When a photographer possesses only one lens, and that of short focus, he unfortunately tries to get as large a picture as possible, and so approaches closer than he would if he used a long-focus lens. Unless he is specially trained, he does not notice, when examining the view, the exaggerated perspective arising from too close a viewpoint, the brain making the objects appear at their correct relative size, whilst binocular vision places them in their correct relative positions. On the plane image these compensations do not exist, and the so-called distortion becomes actually offensive, especially if the image is viewed from a position other than the correct viewpoint (§§ 28 and 31). These anomalies disappear in stereoscopic vision if the images are viewed at the principal distance although the angle of view may then be too large for the eye to view the whole picture without rotating.

When it is stated that a lens of short focus gives "faulty perspective," which should be translated as "geometrically correct but

unpleasant perspective," it is understood, then, that the photographer has clumsily tried to compensate for the smallness of the scale of his image by approaching too close to his subject.

The position of the camera should be chosen without any consideration of scale. If, when the viewpoint is chosen, it is found that the lens is not of sufficient focal length to give directly as large an image as desired, the small image should be subsequently enlarged.

76. Depth of Field. Assuming that the image of a point outside the plane focused on is a circular patch on the image plane, the limits within which the objects should lie in order that these patches (circles of confusion) should be practically indistinguishable from points, can be determined. One cannot stress too much the arbitrary nature of these calculations, which are based on geometrical optics, and which take no account of the distribution of light within the patch. Moreover, it is assumed that the lens is perfect, giving aplanatic, anastigmatic, and plane images, conditions which are unfortunately unattainable. The results of these calculations must be regarded only as indicating in what direction the depth of field changes when the focal length, relative aperture, and object distance are changed. Practical results may differ considerably with objectives of different types; even though the focal length and relative aperture are the same.

It is necessary, first of all, to decide upon the tolerance on sharpness which can be permitted, and this tolerance may either be fixed as an *absolute* value or a *relative* value. In the first case it is usual to fix a maximum value to the diameter of the circle of confusion, of, for example, $1/250$ in., a size which, when viewed at a distance of 12 in. is indistinguishable from a point.

This convention is purely arbitrary, and is too severe for pictures which are to be viewed at a greater distance, as when placed on a wall, and is not sufficiently severe for a small image which has to be subsequently enlarged by projection or examination under a magnifier (the case of stereoscopic pictures). In the second case the maximum diameter of the circle of confusion is defined as a fraction (say, $1/2,000$) of the normal distance of viewing, and therefore of the image distance. This convention is incomparably more logical for pictorial photography than the absolute method.

77. Relative Depth of Field. Let q and q' (Fig. 9.6) be the ultra-nodal distances of the object

plane Q and its conjugate Q' on which the photographic image is recorded, respectively; f/n the relative aperture of the lens, r and s the ultra-nodal distances of point-objects respectively in front of and behind the plane Q , r' and s' the ultra-nodal distances of their focused images.

The dimensions of the circles of confusion in the plane of the image (r) and (s) are expressed by

$$\frac{(r)}{f/n} = \frac{r' - q'}{r'}, \quad \frac{(s)}{f/n} = \frac{q' - s'}{s'}$$

In order that the blurs (r) and (s) should have the maximum permissible diameter aq' (the coefficient a being, for example, $1/2,000$), the distances r' and s' must be such that

$$\frac{naq'}{f} = \frac{r' - q'}{r'} = \frac{q' - s'}{s'}$$

which may be written

$$1/q' - 1/r' = 1/s' - 1/q' = na/f$$

and as (§ 63)

$$1/q' = 1/f - 1/q, \quad 1/r' = 1/f - 1/r \\ 1/s' = 1/f - 1/s$$

it follows that

$$1/r - 1/q = 1/q - 1/s = na/f$$

The difference between the extreme convergences (§ 63) of R and S and the convergence of the plane Q focused on is then represented by $n/2,000$ ths of the power of the lens, all measurements being expressed in diopters; and the total depth of field (distances between R and S measured parallel to the optic axis) corresponds with a difference in convergence equal to $n/1,000$ ths of the power.

For a lens of 4.4 in. focal length, i.e. 0.11 m, or a power of $1/0.11 = 9.09$ diopters, with an aperture of $f/6$, the total tolerance of convergence will be $(9.09 \times 6)/1,000$, or 0.05454 diopters, which has to be divided between the near and far points. If the object focused on was at 197 in. (5 m) with a convergence of $1/5 = 0.2$ diopters, the convergences of the two limits of depth of field will be 0.20 ± 0.02727 , corresponding with object distances of $1/0.22727$ and $1/0.17273$, or 4.40 and 5.80 m (173 and 229 in.) respectively.

It should be noted that the sharp field extends less in front of the plane focused on than behind it (24 and 36 in. in the example above).

A table of reciprocals of numbers from 1 to 1,000 will be useful for making calculations rapidly and of sufficient accuracy in problems relating to depth of field.

It may be said that the depth of field is that part of the object space in which the entrance pupil appears to have an approximately constant angular size, the variations being less than the permitted angle of confusion (A. Jonon, 1925).

Calculations of a similar degree of simplicity enable us to work out the aperture at which the lens must be used in order to give a sharp image of objects at different distances from the lens, and on what plane the lens ought to be focused. The convergences of the extreme points at distances of 80 and 320 in. (2 and 8 m) respectively, are $\frac{1}{80} = 0.0125$ and $\frac{1}{320} = 0.003125$ diopters. The difference is thus 0.009375 diopters. In order that the tolerance in convergence may be equal to this, which represents $375/9.09$ thousandths of the power of the lens (say $41/1,000$) the lens must be stopped down to $f/41$. In practice, the nearest marked aperture of the iris, $f/45$, is used, and this will give ample guarantee of the sharpness and depth required.

The distance to focus on will be given by the mean of the extreme convergences $(0.0125 + 0.003125)/2 = 0.0078125$ corresponding with a distance of $1/0.0078125 \text{ m} = 128 \text{ m}$ (126 in.). That is, $q = 2rs/(r + s)$. This distance is independent of the sharpness tolerance, either relative or absolute, whether based on geometrical or physical considerations.

78. Absolute Depth of Field. To conform to tradition we shall deduce the formulae for depth of field in terms of an absolute diameter of the circle of confusion e (e.g. $e = 1/250$ in.), and not, as above, a constant fraction of the ultra-nodal distance of the plane of the photographic plate.

Assigning a limit e to the diameter of the circle of confusion, and calling (R) and (S) the image patches projected on the plane Q by beams having their apices at R and S, and bounded by the diaphragm, we find, in the same notation as above, that

$$\frac{R}{f/n} = \frac{q-r}{r}, \quad \frac{S}{f/n} = \frac{s-q}{s}$$

If the image Q' of the plane Q is reduced on a scale $1/m$, which implies that $q = (m+1)f$, the diameters (r) and (s) of the images are equal to (R)/m and (S)/m respectively. If these are to be equal to the maximum diameter e , then

(R) and (S) are equal to me , and r and s (the distances of the near and far planes which will be rendered sharply) will be calculated from

$$\frac{em}{f/n} = \frac{q-r}{r} = \frac{s-q}{s}$$

$$q/r = 1 + nme/f, \quad q/s = 1 - nme/f$$

whence, after simplification

$$r = \frac{(m+1)f^2}{f + nme} \quad s = \frac{(m+1)f^2}{f - nme}$$

Using the same numerical values as in the previous example, all distances being reduced to metres and taking $1/250$ in. (0.01 cm) as the maximum diameter of the circle of confusion, we shall find, for the case of an object at 197 in. (5 m), $s = 660$ cm (260 in.), giving a more extensive field of sharp definition than previously calculated, because the tolerance of definition is much greater in this case.

79. If the camera carries a scale by which the change in camera extension can be measured, the above calculations can be avoided.

Having focused successively the near and far planes and noticed each time the position of the movable part on the scale, the camera is set to the mid-way position and will then be correct. To obtain a degree of sharpness equal to $1/250$ in., the $f/\text{No.}$ is taken as one-eighth the number of thousandths of an inch the camera extension has been altered (G. Cromer, 1911).

If, for example, the movement is 0.16 in., the aperture will be $f/20$.

For a sharpness of $1/125$ in. or $1/500$ in., half or double the above number must be taken, i.e. $f/10$ or $f/40$ respectively in the above case.

80. Factors Affecting Depth of Field. The depth of field (distance between near and far planes in focus) can be expressed by one or other of the following formulae, according as the permissible circle of confusion is a constant fraction a of the distance of the image, or a fixed amount e . The formulae give the difference $(s-r)$ of the distances previously calculated—

$$(1) \frac{2naq^2f}{f^3 - n^2a^2q^2} \quad (2) \frac{2naq(q-f)f^2}{f^4 - n^2e^2(q-f)^2}$$

in each of which the second term of the denominator is generally negligible unless q is very great, so that we can replace these by the simpler formulae below, which lead to a slightly smaller value—

$$(1A) \frac{2naq^2}{f} \quad (2A) \frac{2naq(q-f)}{f^2}$$

In this form it is seen at once that, all conditions remaining the same, with the exception of the one factor considered—

1. Depth of field is less with a lens of greater focal length; it is inversely proportional to f if the tolerance is defined as an angular constant, and inversely to the f^2 when the tolerance is fixed by an absolute value.

2. Depth of field is proportional to n and is thus greater the smaller the stop.

3. Depth of field is greater for greater object distances, being proportional to the q^2 .

4. Depth of field, based on the value of a or e , is greater the less exacting the requirements of definition are.

It should be noted that the laws of physical optics lead to the result that the relative depth of field is independent of the focal length f , and is inversely proportional to the square of the diameter of the effective aperture (T. Smith, 1928).

81. It is interesting to know, at least from a practical point of view, if, having to photograph an object of a certain depth, from a given point of view, a lens of focus to give a required scale of image can be used, or whether it is preferable to use a lens of very short focus, giving a small image which is afterwards enlarged.

Taking the same numerical data as in § 77, but supposing this time that the focal length is 13.2 in. (0.33 m), or a power of 3.03 diopters, we will find the depth of field for the same circle of confusion after equalization of the sizes of the two images. The distance of the plane focused on being the same in the two cases, the sizes of the two images are proportional to the respective ultra-nodal distances, and it will be sufficient to give a the same value, 1/2,000. The total tolerance of convergence is thus found to be $(3.03 \times 6)/1,000 = 0.0182$ diopters, and consequently the convergences of the limits of the field are (0.2 ± 0.0091) diopters, corresponding with ultra-nodal distances of $1/0.2091 = 4.78$ m (188 in.) and $1/0.1909 = 5.24$ m (206 in.) with a total depth of field of 18 in. only, instead of 48 in. in the case of the lens of 4.4 in. focal length.

It remains to examine whether, to obtain a reproduction at the same size by direct photography, supposing that aesthetic considerations allow an alteration of viewpoint, there is any advantage as regards depth of field, in using a lens of shorter focus, or if, on the contrary, it is preferable to get farther back from the view and use a long-focus lens.

From the formulae of § 77, remembering that $q = (m + 1)f$, it is possible to deduce the expression for the total depth of field ($s - r$)

$$s - r = \frac{2af(m+1)^2n}{1 - (m+1)^2a^2n^2}$$

The scale of reduction m being constant, the camera extensions are proportional to the focal lengths, and in order to have the same limits for the diameter of the circle of confusion in the photographs taken with lenses of different focal lengths, the product af must be constant = k (say), whence $a = k/f$, and the above expression reduces to

$$s - r = \frac{2k(m+1)^2n}{1 - (m+1)^2n^2(k/f)^2}$$

The $f/\text{No. } n$ being supposed constant, it is seen that, if f increases the denominator increases and ($s - r$) decreases.

82. **Hyperfocal Distances.** Particularly interesting problems in the application of the depth of field formulae are the determination of the distance at which the lens must be focused in order that the far plane in focus may be at infinity, and the finding of the distance of the near plane in these circumstances.

The distance of the plane focused on which satisfies this condition for a lens of given focal length and aperture, is usually called the *hyperfocal distance for that aperture*. Let it be said at once that the hyperfocal distance will have different values according to the degree of unsharpness which can be tolerated.

If we agree to adopt as the tolerance a constant fraction a of the ultra-nodal distance of the image (still supposing that the pupils coincide with the nodal points), the hyperfocal distance H of a lens of focal length f and aperture number n , is easily calculated if we consider that the convergence of the far plane is zero, this being at infinity. Calling l the distance to the near plane, the preceding formulae for the depth of field become

$$1/l - 1/H = 1/H = na/f$$

whence $H = f/na$ and $l = f/2na = H/2$

Thus the distance H on which a lens of focal length 4 in. should be focused, at an aperture of $f/5.6$, in order to give a sharp image of an infinite object, assuming $a = 1/1,000$, is

$$H = \frac{4 \times 1,000}{5.6} = 714 \text{ in.} = 60 \text{ ft approx.}$$

The camera, when focused for this distance, would give equally sharp images from 30 ft to infinity.

It may be remarked that when the limit of sharpness is defined by an angular value the hyperfocal distance is proportional to the focal length and inversely proportional to the f/No . It is also greater the more severe the standard of good definition is.

This is easily explained by noticing that the *hyperfocal distance* thus defined is the *distance from which the effective aperture subtends the angle of tolerance*. If, for example, the angle is $1/2,000$ (circle of confusion = $1/2,000$ of the

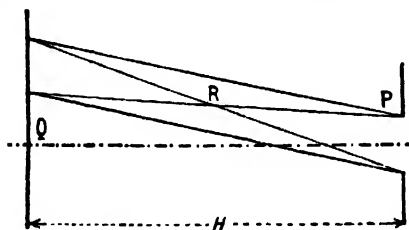


FIG. 9.7. GEOMETRY OF HYPERFOCAL DISTANCE

principal distance), the hyperfocal distance is 2,000 times the useful aperture of the stop. Similarly, if the angle were $1/1,500$ or $1/1,000$, the hyperfocal distance would be 1,500 or 1,000 times the useful aperture.

83. If we agree to adopt, as limit of definition, a diameter e for the circle of confusion, we calculate H by the condition that s is infinitely great, which requires the denominator of the fraction for s (§ 78) to be zero. so

$$f = nme, \text{ whence } m = \frac{f}{ne}$$

As the plane focused on, reduced in the ratio $1/m$, is at an ultra-nodal distance $(m + 1)f$, we get $H = f(f/ne + 1)$, and for the corresponding length l , by replacing m by the value above in the expression for r ,

$$l = H/2$$

If instead of measuring H from the front nodal point, we measure it from the front focal point, we get

$$H' = f^2/ne$$

It may be remarked that, when the limit of sharpness is thus defined as an absolute value, the hyperfocal distance is, for equal relative apertures, proportional to the square of the focal length, i.e. for lenses of focal length half,

double or triple that of the lens in the example, the hyperfocal distances would be respectively one-quarter, four times, and nine times, the value calculated above.

If the diameter of the aperture is reduced to half or one-quarter its value, the hyperfocal distance will be reduced to half or quarter the value calculated above.

If, instead of fixing the limit at $1/250$ in., it was taken as $1/125$ or $1/500$ in., the hyperfocal distance would be half or twice respectively the former value.

In every case the distance of the near plane is half the hyperfocal distance.

84. The formula for hyperfocal distance can be obtained directly without using the formulae for depth of field.

Let P be the entrance pupil of the lens (Fig. 9.7). Every parallel pencil of light (i.e. coming from an infinitely distant point) will cut planes perpendicular to the axis (and Q in particular) in a circle of the same diameter as that of the pupil. The beam, limited by the pupil and having as apex any point R half way between Q and the pupil, cuts Q in a circle of the same size (which will coincide with the former if R is on the principal ray of the beam). If we focus the lens on Q , the condition that all point-objects from R to infinity shall be sharp is that the images of the circles on Q , reduced $1/m$ th, must not exceed the limit e assigned to the diameter of the circle of confusion. Now, the diameter of the pupil is f/n ; the condition is therefore $f/n \times m = e$, and gives $m = f/n \times e$, whence, the distance H of the plane reduced $1/m$ th being $(m + 1)f$,

$$H = (f/ne + 1)f$$

85. Influence of the Corrections of the Lens on the Depth of Field and Hyperfocal Distance. It cannot be too strongly emphasized that the depth of field and hyperfocal distance calculated from the formulae given in the foregoing paragraphs, or taken from charts and diagrams based on them, have only relative accuracy. It may be noted in passing that few of these tables indicate the degree of sharpness on which they are based.

Firstly, it was assumed in deducing the formulae that the nodal points coincided with the centres of the corresponding pupils, which is not always true, particularly for telephoto lenses.

Secondly, it was assumed that the lens was ideal, having a flat field free from all aberrations.

Thirdly, it was assumed that the circles of confusion were uniformly illuminated. Actually

a patch of light of large area can give a reasonably sharp image if there is a concentration of light at its centre.

These formulae lead to the conclusion that depth of field is the same for different lenses of the same focal length and aperture, a conclusion which is not always borne out in practice. In fact a perfectly corrected lens has less depth of field than one having residual aberrations (D. Brewster, 1867).

Compare, for example, two lenses of the same focal length and aperture, one, *A*, free from spherical aberration, the other, *B*, having positive spherical aberration at apertures greater than $f/16$. The aberration of *B* being positive, the caustics of each beam will be formed between the sharpest image and the lens, approaching the latter as the aperture increases, and thus affecting only the lower limit to the depth of field. At $f/16$ the lenses give equal depth; at an aperture slightly larger the caustics due to spherical aberration make their appearance with *B*. A beam limited by a caustic would be restricted more rapidly than one limited by a cone, so that the depth of field would diminish less quickly with the uncorrected lens. If objects situated in front of or behind the focused plane are considered, this difference between the two lenses increases as the aperture is increased. At a certain aperture the caustic, meeting the sensitive surface, gives practically a constant circle of confusion, and thus sets an almost invariable lower limit to the depth of field, whilst with the perfect lens every increase of aperture increases the diameter of the circles of confusion, and thus limits the depth of field. A negative aberration would affect the back limit in the same way (C. Welborne Piper, 1903).

It has been suggested that to increase the depth of field, one of the lens elements should have an aspherical surface to provide over-correction of spherical aberration in the central zone and under-correction in the marginal zone (A. Warmisham, 1932).

86. Fixed-focus Cameras. In many very cheap cameras for beginners, no adjustment for focus is provided. The lenses used on these cameras being nearly always simple or achromatic, very poorly corrected, with maximum aperture rarely exceeding $f/16$, the hyperfocal distance is very short, and consequently the minimum distance of sharp objects (half the hyperfocal distance) is small enough to allow almost all subjects (except portraiture, properly so-called) to be attempted.

In addition to this category of cheap cameras with fixed focus there is a second category of very short-focus lenses of high aperture which are also used at a fixed focus. Examples of this may be found in sub-standard cinematography.

Reducing the aperture in fixed-focus cameras does not make use of all the increased depth of field, since the lens ought then to be refocused for the new hyperfocal distance.

This interesting property of lenses of short focus and small aperture has frequently given rise to the unfortunate expression *fixed-focus lens*, which has led to much misunderstanding. It must therefore be insisted that this action is not the result of any special form of lens, but of the general application of the laws governing depth of field.

87. Focusing Scales. Portable cameras for use in the hand generally are not suitable for focusing the image on a focusing screen, and are therefore provided with a scale graduated in object distances so that the focus can be set for any distance within the limits of the scale.

The mark on this scale corresponding with objects at a great distance (generally indicated by ∞ , or the letters "INF" usually indicates the focal plane for objects on the horizon, and, sometimes, the focus for objects at the hyperfocal distance of the lens at the maximum aperture (usually adopting $1/250$ in. as the circle of confusion). Some makers indicate the focus both for infinity and the hyperfocal distance, the latter being indicated by a mark of different colour or the letter *H*. It must be remembered that when the focus is set for infinity the nearest plane that is sharp is at the hyperfocal distance, while when focus is set for the hyperfocal distance the nearest plane that is sharp is at half this distance.

The distances on the scale are often chosen quite arbitrarily. It would be better to divide the hyperfocal distance (allowing $1/2,000$ the camera extension as the circle of confusion) by the consecutive numbers 0, 1, 2, 3, . . . , i.e. infinity, the hyperfocal distance, half, one-third, one-quarter, . . . the hyperfocal distance. Such a scale possesses an interesting property when used with the appropriate diaphragm and when the tolerance of sharpness used in its construction is accepted. When the focus is adjusted for one of the distances on the scale, the depth of field extends to the contiguous distances.

If, for example, the lens is of 5 in. focal length and $f/8$ aperture (hyperfocal distance 788 in. for a circle of confusion of $1/250$ in.), and the

scale is marked ∞ , 66', 33', 22', 17', 13', 11', 9' 5", 8' 3", 7' 4", 6' 7", 6', 5' 6", 5' 1", 4' 8", 4' 4", 4', etc., when set for 13' all objects between 11' and 17' will be sharp.

It is the practice with some manufacturers to attach a depth of field scale to the focusing mount of the lens, so that the limits of the sharp field are indicated for any focusing position.

88. Depth of Focus. If the plane on which the image is formed is slightly separated from the position of the sharp image of a point, the

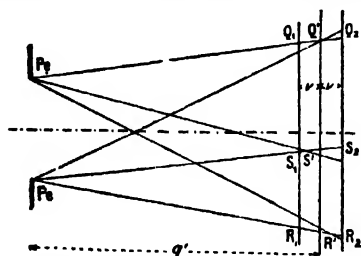


FIG. 9.8. DEPTH LATITUDE IN THE FOCAL PLANE

image will be a disc which can be considered as a geometrical point if its diameter does not exceed a certain fraction a of the ultra-nodal distance of the sharp image, or does not exceed a constant limit ϵ (§ 76).

Knowing (Fig. 9.8) the diameter of the aperture f/n and the ultra-nodal distance q' of the focused image (supposing again that the pupils coincide with the nodal planes) it is easy to calculate the distance v , the error in the position of the plate which can be tolerated. Calling the diameter of the disc of confusion at Q_2 (Q'), consideration of the similar triangles having their apices at Q' gives

$$\frac{(Q')}{f/n} = \frac{v}{q'}$$

Now, according to the convention adopted in fixing the tolerance in sharpness, we have

$$(Q') = aq' \quad \text{or} \quad (Q') = \epsilon$$

which gives¹

$$v = \frac{q'^2 \times a}{f/n} \quad \text{or} \quad v = \frac{\epsilon q'}{f/n}$$

The tolerance is the same in front and behind the focus.

¹ Considerations of physical optics ascribe to depth of focus a value proportional to the wavelength of the radiation and expressed as $h\lambda \left(\frac{q'}{F/n}\right)^2$

The sum of these equal tolerances is the *depth of focus*, a term which is often erroneously used when depth of field is meant.

This tolerance is greater the smaller the useful aperture of the stop (other things being equal). When, for an equal stop, the image is formed at a greater distance (e.g. in photographing a nearer object or using a longer focus lens) the tolerance in focusing is greater.

It is necessary to add that this latitude can only be made use of in photographing plane objects perpendicular to the axis, or in the photography of objects of negligible depth. *It is impossible to make use of depth of focus and depth of field at the same time.*

If images at R' and S' of points in front of and behind Q are also to be photographed at the same time as Q' it is seen that they will form image patches in one of the limiting planes, of diameter greater than the tolerance.

In particular it should be remembered that depth of focus has already been taken into account when a lens having curvature of field is used.

89. Effect of Relative Aperture on the Brightness of the Image. In the photography of a landscape in which all the objects are at a very great distance from the lens, the brightness of the image at the centre of the field (on the optic axis) is, apart from loss by absorption and reflection (§ 58), inversely proportional to the square of the relative aperture f/n (§ 71). It is easily seen that for equal losses in passing through the lens, two lenses, of the same focal length but of different effective apertures, give images the brightnesses of which are proportional to the area of the effective aperture, which, in fact, limits the beam of light from a distant object, just as a tap restricts the amount of liquid passing through. If the diameter of the effective aperture is doubled its area will be four times as great. The images being of the same size, since the focal length is assumed to be the same in each case, the brightness will vary in the same ratio.

Let us now consider two lenses of the same effective aperture but of different focal lengths. If the focal length of one is double that of the other, all dimensions in the plane of the image of distant objects will be doubled, and consequently the areas will be four times as great. Both will receive the same quantity of light, but that formed by the longer-focus lens will be one-quarter as bright, so that the brightness of the image is directly proportional to the

square of the diameter of the lens and inversely proportional to the square of the focal length.

If B is the brightness of an element of the object situated on the axis and perpendicular to it, the intensity of illumination of its image is $E = \tau n B / 4n^2$ where τ is the transmittance.

In complex systems the losses by reflection and transmission minimize the apparent advantage of high aperture. The table below shows the results of measurements made by C. Forch and F. Lehmann (1928) on a number of lenses of different nominal relative aperture, indicating a wide variation in the transmittance.

Attempts have been made to overcome variations in transmittance between lenses of the same f /numbers by adopting a method of calibration known as the T -stop system (1949). The T -number of a lens is the f /number divided by the square root of the transmittance, i.e.

$$T\text{-No.} = n/\sqrt{\tau}$$

The image illumination formula given above thus becomes

$$E = B/4(T\text{-No.})^2$$

Lenses calibrated in T -stops have found favour in the motion picture industry, where it is most desirable that interchangeable lenses can be used without upsetting exposure. On the other hand, since the T -stop is not directly correlated with the geometry of the lens system, the T -stops cannot be used for the determination of the depth of field (§ 76), and for this reason it is unlikely that the T -stop system will find universal adoption.

Relative aperture indicated	Relative aperture measured	Equivalent aperture		Transmission %	
		Ordinary plate	Ortho-plate with yellow filter	Ordinary plate	Ortho-plate with yellow filter
$f/2$	$f/2.1$	$f/3.1$	$f/2.7$	46.6	60
$f/2$	$f/2.48$	$f/3.26$	—	58.1	—
$f/1.5$	$f/1.75$	$f/2.82$	$f/2.18$	38.7	65.2
$f/4$	$f/3.92$	$f/6.2$	$f/5.05$	40	60.5
$f/4.5$	$f/4.73$	$f/5.94$	$f/5.47$	63.5	75

It should be noted that a proportion of the light lost by reflection finds its way to the image plane as a veil of haze. L. V. Chilton (1937) found the ratio of this parasitic illumination to the useful illumination for a number of lenses, and found the following results for different numbers of air/glass surfaces.

No. of air/glass surfaces	2	4	6	8	10	12
Percentage of parasitic illumination	0.245	1.42	3.40	6.08	9.44	13.95

We shall conclude, then, by saying that the speed of a lens is chiefly determined by its relative aperture, and that of two lenses of apertures $f/7$ and $f/9$, for example, the first gives an image which at its centre (neglecting loss of light) is brighter than the second in the ratio of $(f/7)^2/(f/9)^2 = 9^2/7^2 = 81/49 = 1.65$.

In particular, if the stops of a lens have their diameters in geometrical progression with a ratio of 1.414, i.e. are proportional to the numbers

$$1 \quad 1.414 \quad 2 \quad 2.818 \quad 4 \quad 5.636 \quad 8 \quad 11.27 \dots$$

the areas of the corresponding circles will be doubled at each step, and the illumination at the centre of the image will be doubled when any stop is replaced by the next larger.

90. **Effect of the Scale of an Image on its Brightness.** If an object, illuminated equally in all cases, is photographed several times with the same lens at the same aperture but on different scales, by moving the lens closer and closer to the object, it will be found that the image falls off in intensity as the size increases.

The image illumination formula then becomes

$$E = \frac{\tau n B}{4n^2(1+m)^2}$$

This amounts to saying that when the image is formed, not in the focal plane, but at a distance $(m+1)f$ from the near nodal point, the relative aperture of the stop f/n is reduced to $f/n(m+1)$. This assumes that the entrance pupil contains the front nodal point; in all other cases, the scale m should be replaced by $m(1+\mu)$ where μ is a small quantity, positive for a telephoto objective, and negative for a simple lens with the diaphragm in front. In practice the value of μ is nearly always sufficiently small for the above rule to be valid.

As a particular case, if an object is photographed under the same illumination from a great distance, so that its image can be considered as lying in the focal plane, and again at a short distance, so that its image is the same size as itself, the intensity of illumination of the second image will be one-quarter of its value in the first.

91. Marking of Aperture Scales. Although there is almost universal agreement on the marking of aperture scales, a number of different systems have been suggested and used from time to time. A comparison table of a number of

systems is given below. The most common system follows the series— $f/0.7$, $f/1$, $f/1.4$, $f/2$, $f/2.8$, $f/4$, $f/5.6$, $f/8$, $f/11$, $f/16$, $f/22$, $f/32$, $f/45$, $f/64$.

The true apertures should follow the series— $f/1/\sqrt{2}$, $f/1$, $f/1/\sqrt{2}$, $f/2/\sqrt{2}$, etc., whereas the numerals quoted above represent, in some cases, approximate values (for example, $f/11$ should really be $f/11.27$). The maximum aperture may not necessarily fall into this series; for example, popular maximum apertures are $f/3.5$, which falls between $f/2.8$ and $f/4$, and $f/4.5$, which falls between $f/4$ and $f/5.6$. The British Standards Institution recommend that the marking of the maximum aperture should be within ± 5 per cent of the true relative aperture.

COMPARISON OF APERTURE SCALES

<i>f</i> -number	Relative Light Passing Power	Decrease in Light Passing Power (Nearest 1/3 Stops)
1	10,000	0
1.1	7,937	1
1.2 (1.3)	6,300	2
1.4 (1.5)	5,000	3
1.6	3,969	4
1.8	3,150	5
2 (1.9)	2,500	6
2.2	1,984	7
2.5	1,575	8
2.8 (2.9)	1,250	9
3.2	992	10
3.5	788	11
4 (3.8)	625	12
4.5	496	13
5	417	14
5.6	312	15
6.3	248	16
7	209	17
8 (7.7)	156	18
9	124	19
10	104	20
11	79	21
12.5	62	22
14	52	23
16	40	24
18	31	25
20	26	26
22	20	27
25	16	28
28	13	29
32	9.9	30
36	7.8	31
40	6.5	32
45	5.0	33
48 (50)	3.9	34

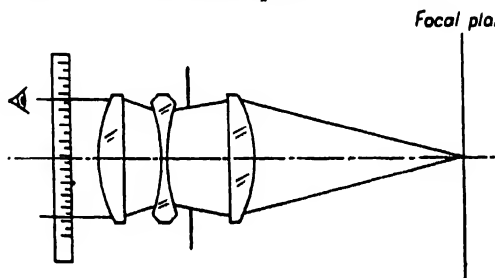


FIG. 9.9. MEASUREMENT OF EFFECTIVE APERTURE

92. The Measurement of the Effective Aperture. The effective aperture of a lens can be measured by placing a small source of light (such as an illuminated pinhole) in the centre of the focal plane. If a rule is then placed perpendicular to the axis of the lens, the free diameter can be measured (Fig. 9.9). A permanent record can be made by placing a photographic plate in front of the lens, when after development a black disc corresponding to the free aperture will be obtained. It should be noted that it is necessary to measure the focal length fairly accurately in order that the relative aperture may be calculated.

CHAPTER X

CHOICE OF A LENS: TESTING: CARE OF LENSES

93. **Preliminary Remarks.** The qualities required of an objective depend on whether the lens is intended for artistic photography, commercial photography, process work, enlargement or photogrammetry (measuring by photography). The optical designer has at his control the curvatures, refractive indices and dispersions; thickness and separation, and can vary these to correct for certain aberrations. It is not possible to reduce all aberrations to small proportions simultaneously, and every lens therefore represents a compromise. For specialized purposes the designer attempts to minimize those aberrations which would be most harmful, and such a lens might not perform satisfactorily when used for another purpose.

94. In pictorial photography, a simplified image is required, to give "firm" drawing without hardness, of breadth proportional to the scale of the image, and to suppress all unnecessary detail, translating only the general form. "When an artist paints from Nature he removes his eyeglasses if he is short-sighted; if he has good sight he half-closes his eyes, otherwise he would not see the tree for the leaves nor the forest for the trees" (C. Puyo). This simplification is best achieved by the use of lenses incompletely corrected for spherical aberration, or, better still, uncorrected for achromatism (*anachromatic* lens). The fact that a very wide angle of view is never used in pictorial work prevents the oblique aberrations (astigmatism, coma, curvature of the field) from being very harmful, the more so as, to obtain a sufficiently uniform image in the different planes, small apertures must be used. Such lenses can, therefore, be made very simply, even from lenses made for other purposes, so long as combinations practically free from distortion are employed, in which spherical aberration is small, if not entirely removed. The modern tendency, however, is to use lenses which are capable of giving good definition for producing the negative, introducing whatever softening is desired in the printing process.

Certain requirements, chiefly commercial, such as the necessity of being able to make extremely short exposures under all lighting conditions, compel the professional photographer

to possess, at least as auxiliary instruments, lenses of the greatest speed compatible with the great focal lengths which are necessary, if the photographer is not to approach too close to his sitter and so distort the image by exaggerated perspective. Some of these lenses giving normally a sharp image for a scale of reduction from $1/2$ to $1/10$, include an element the separation of which from the other components can be modified by the rotation of a ring, thus introducing into the image certain aberrations to soften the contours (J. Traill Taylor, 1892).

The commercial photographer and the press photographer, who are often unable to choose the most favourable viewpoint (i.e. to get sufficiently far away from the subject) are generally obliged, at least for a great amount of their work, to use lenses having a very large field (called *wide-angle* lenses), and giving thus very sharp images without the necessity of stopping down greatly. Press work, and especially sports photography, requires the use of a very large-aperture lens.

The process worker requires to obtain a plane image of a plane object, free from distortion within the limits of scale usually employed (same size or a little smaller). There is no need, in this case, for a large aperture, but the chromatic corrections need to be very good if three-colour work is to be done; the different component pictures obtained through selective filters should be capable of being exactly superposed and be of equal sharpness.

The requirements of a lens for enlarging are much the same as those for process work, except that the correction should be made for an enlargement of 2 to 15 times linear.

A lens for photo-topography (photography applied to topographic survey work) should embrace a very wide angle and give a perfect image of distant objects (corrections therefore limited to an infinite object distance) and, especially, absolute freedom from distortion and curvature of the field. For work executed from terrestrial stations, a small aperture is sufficient, but for aerial photography, where large apertures are required, the angle of field is usually smaller, and the correction for achromatism may be a simpler matter, since a yellow filter, which is

always necessary in this class of work, may be permanently incorporated with the lens.

Finally, it may be noted that for certain classes of work (e.g. astronomy) requiring either very high apertures, or very long focal lengths, objectives incorporating mirrors are used (*catadioptric systems*).

95. Brief Description of the Principal Types of Lenses. In the following paragraphs are briefly described some types of lenses, chosen as those which have marked an epoch in the development of photographic optics, with an indication of their essential characteristics, but

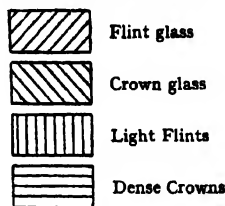


FIG. 10.1. SHADING REPRESENTING THE DIFFERENT TYPES OF GLASS

without claiming to be a complete list, on account of the extremely wide variety of combinations in use and the continual improvements being made. To facilitate comparisons, all the sectional drawings (Figs. 10.2 to 10.26), reduced to their essential elements, have been made on a uniform scale corresponding to lenses of 4 in. focal length. The principal types of optical glass are indicated by conventional shading, the key to which is given in Fig. 10.1. The stop drawn corresponds approximately to the maximum aperture.

96. Single Lenses. The simple non-achromatized lens was used in the camera obscura before the invention of photography. To obtain a relatively large field, W. H. Wollaston (1812) recommended the use of a convergent meniscus lens (Fig. 10.2), with stop in front, having an aperture of $f/11$, and covering a field equal to the focal length (angle 60°). This image, it must be understood, has every possible aberration, and in particular requires the adjustment after focusing to compensate for the difference between visual and chemical focus. In some fixed-focus cameras (§ 86) this is made once for all by the maker who also makes allowance for astigmatism, field curvature and coma by setting the film at a suitable distance from the lens.

The first photographs made by Daguerre were taken with a doublet lens made by C. L.

Chevalier (1830), partially corrected for achromatism (Fig. 10.3), which, with stop $f/14$ (afterwards increased to $f/12$), covered sufficiently well a circle of diameter equal to half the focal length. At a smaller stop, $f/70$, the field was half as large again.

This form of lens was improved and brought to its present form of simple achromatic lens only in 1857 by Thomas Grubb. In his lens (Fig. 10.4) it is seen that the arrangement of Chevalier was reversed, the convergent lens this time facing the object. With an aperture, usually $f/16$, the field reached 60° with complete correction of achromatism and partial correction of spherical aberration for the central rays. By increasing the number of cemented lenses to three (Fig. 10.5), J. H. Dallmeyer (1865) was able to extend the aperture to $f/11$ and field to 70° (90° at $f/32$) in his "rapid wide-angle landscape lens."

97. Petzval Portrait Lens. This lens (Fig. 10.6), the first to be calculated by a mathematician, was only moderately successful when first brought out (1840). J. Petzval set out, by a proper choice of curvatures and thicknesses, to correct aberrations, and particularly curvature of the field, without the necessity of using a small stop, so as to shorten the very long exposures required in the Daguerreotype process. But this aim could only be accomplished at the expense of angle of field, the diameter of useful field being only about one-third the focal length (angle 20° to 25°), with an effective aperture of $f/3.4$ to $f/3.6$, subsequently enlarged to $f/2.4$ by H. Zincke in 1870. It will thus be seen that the useful field of the lens was almost equal to its diameter. Although this angle of field was quite sufficient for the head-and-shoulders portrait, as experience has since shown, the tendency of the time was towards a very large angle of field, and the photographer would almost have liked the lens to portray objects behind it!

In his first type Petzval had intentionally left in a little chromatic aberration, which subsequent optical designers adopting this type corrected in the endeavour to make the image a little more homogeneous.

The Petzval portrait lens, more or less modified, is still in use in a large number of portrait studios. Perhaps it would also be used by amateurs if it had not been for the tradition of



FIG. 10.2. WOLLASTON'S SINGLE MENISCUS, $f/11$

mounting it in an extremely cumbersome mount. It is frequently also used for projection work.

At the time of the reaction against the exaggerated correction of lenses for portraiture, lenses of the Petzval type were successfully used (de Pulligny, 1904) with the back combination removed and replaced by a simple convergent

was indeed rectilinear, it was only very slightly aplanatic, so that it is the name given it by Dallmeyer that has become general for this class of lenses, which all lens designers tried, more or less successfully, to improve. In its original form it covered a field of 45° at $f/8$, and 60° at $f/30$. Steinheil succeeded in increasing the

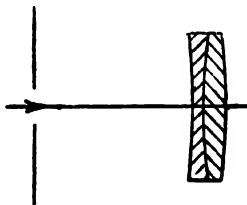


FIG. 10.3. CHEVALIER'S
DOUBLET LENS
 $f/14$

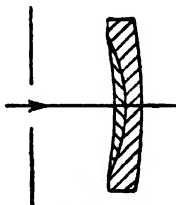


FIG. 10.4. GRUBB'S
DOUBLET LENS
 $f/16$

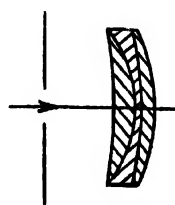


FIG. 10.5. DALLMEYER'S
LANDSCAPE LENS
 $f/11$

meniscus of the same diameter but almost double the focal length. The whole lens can be used at about $f/5$. The chromatic fringe is then about one-third to one-quarter that of an anachromatic lens of the same focal length and relative aperture.

98. Rectilinear Lenses. At a time when the only successful lenses available to the photographer were the simple objective and the

aperture to $f/7$ and even $f/6$ without much sacrifice of field (40°). These lenses attained considerable popularity.

If the aperture of a rectilinear lens is increased beyond its normal limits, spherical aberration is introduced, and gives the image a softness comparable, to a certain degree, with that given by the introduction of chromatic aberration, so that the lenses are sometimes so used for

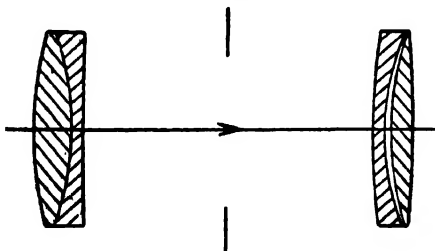


FIG. 10.6. PETZVAL PORTRAIT LENS,
 $f/3.5$

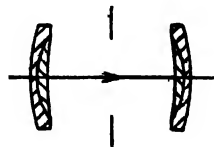


FIG. 10.7. STEINHEIL'S SYM-
METRICAL APPLANAT, $f/8$

portrait lens, the need was felt for lenses covering a field comparable with that of the single lenses but perfectly corrected for distortion, which consequently could be used for copying and architectural photography. This correction was sought for in a symmetrical arrangement of the components, following that already used by Wollaston for microscope objectives. In 1866 H. A. Steinheil brought out his symmetrical aplanat (Fig. 10.7), and soon afterwards the rectilinear of Dallmeyer appeared, almost identical except as to detail. However, while this lens

portraiture. No correction for focus is then necessary.

An important advantage of the rectilinear lens for the possessor of a camera having sufficient bellows extension is the possibility of using the back combination alone, forming a single achromatic lens of double the focal length of the complete lens. The largest aperture, $f/8$, is then actually $f/16$ or a little less. The image is almost twice as large as that obtained with the complete lens, but is only one-quarter as bright. A little distortion may be seen at the

edges of the field, which need not prevent its use as a landscape lens. The rectilinear is thus the cheapest and simplest *convertible lens*.

99. Wide-angle Rectilinears. The somewhat large separation between the components of the rectilinear lens restricts the angle of field illuminated, and it is impossible, even by stopping down, to increase the angle to the extent required in many classes of work. In the 'sixties were introduced the Globe lens of Harrison and Schnitzer (1863) and the Pantoscope of Busch (1866), symmetrical combinations of two achromatic lenses of the form shown in Fig. 10.2, covering 90° and 95° at maximum apertures of $f/17$ and $f/30$, with considerably

tion of the individual components, each component, on the contrary, being left with considerable aberration, which compensated that in the other. This fruitful conception was first applied with real success by A. Steinheil (1881) in his group antiplanat (Fig. 10.10), covering at $f/6.2$, the central region being remarkably well corrected for astigmatism. The considerable weight of this lens was a serious drawback to its use on the light cameras which began to be fashionable with the introduction of the dry plate. Hence this lens and several variants of it made by R. Steinheil merely aroused curiosity, the more so as the approaching appearance of the anastigmat was to furnish a



FIG. 10.8. STEINHEIL'S
WIDE ANGLE, $f/18$

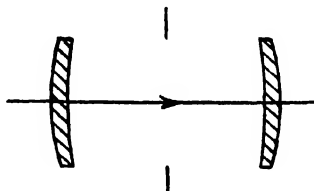


FIG. 10.9. PUYO AND PULLIGNY'S
SYMMETRICAL ANACHROMATIC
LENS, $f/6.5$

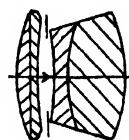


FIG. 10.10 STEINHEIL'S
GROUP ANTIPLANAT,
 $f/6.2$

less curvature of the field in the latter case. Steinheil subsequently succeeded, by modifying his applanat but keeping the same principle, in making his wide-angle applanat (Fig. 10.8), covering 105° at $f/18$, showing marked superiority over its predecessors, particularly from the point of view of spherical aberration.

100. Anachromatic Symmetrical Lens. This lens, the use of which was recommended by Puyo and de Pulligny (1903), is based on Steinheil's "Periscope" but, there being no need for a large angle of field, the aperture was increased from $f/40$ to $f/6.5$. The symmetrical anachromatic consists of two identical convergent menisci placed one on either side of the stop, with their convex surfaces outwards and separated by at least one-sixth of their common focal length (Fig. 10.9). When the necessary correction is made for focus, very agreeable portraits can be made, covering a field of about 30° .

101. Antiplanats. A symmetrical construction reduces the resources of the lens designer in the matter of corrections, as both combinations must be separately corrected for several aberrations. With the glasses available at this period progress was only possible by giving up both symmetry and the separate correc-

complete and more elegant solution of the problem of the photographic objective.

102. The First Anastigmats. The principles of the correction of astigmatism had been laid down in 1843 by Petzval, but none of the glasses available to opticians at that time allowed these conditions to be satisfied. The appearance of new glasses, dense crowns, and light flints, enabled P. Rudolph, at the instigation of E. Abbe, to design, after less successful attempts, a type of unsymmetrical, unconvertible doublet, the appearance of which (1890) marks an event in the history of photographic optics, at least as important as the invention of the portrait lens or the applanat. Each of the components of the different series of lenses made on the same principle (afterwards known as Protars) was formed of two cemented glasses, the dimensions, curvatures, and thicknesses varying as the requirements were for a lens of high aperture (field of 80° at $F/7.2$) or one of very large field (110° at $f/18$). Fig. 10.11 shows this type of wide-angle lens. A much better correction of astigmatism was obtained in 1893 by adding a glass to the rear component (Fig. 10.12), this lens covering perfectly, without curvature of field, an angle of 57° at $f/8$ and still satisfactorily

75° when stopped down to $f/22$. In 1901 H. L. Aldis showed that an excellent image could be obtained with a considerably simpler construction (Fig. 10.13), covering a field of 51° at $f/6$ and 90° at $f/32$.

103. Convertible Anastigmats. The excellent results obtained by Rudolph encouraged many lens designers to use the new combinations of glasses, but they sought for a solution of the problem in another direction—returning to

and curvature, but very suitable for landscape work. The focal length is usually about 1.8 times that of the complete lens, and the camera extension is rather more than doubled. The maximum effective aperture is then equal to the actual diameter of the largest stop, and the relative aperture about 40 per cent (mean value) less than that of the complete lens.

Meanwhile (1895) Rudolph, after having tried and rejected this arrangement, worked out a



FIG. 10.11. RUDOLPH'S
WIDE-ANGLE PROTAR,
 $f/18$

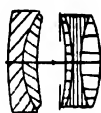


FIG. 10.12 RUDOLPH'S
PROTAR, $f/8$



FIG. 10.13. ALDIS
ANASTIGMAT, $f/6$

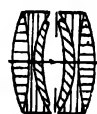


FIG. 10.14. VON HOEGH'S
DAGOR, $f/6.8$

the convertible symmetrical lens. The German factories being almost the only ones at this period to possess research departments, the first of the new category to appear was the double-anastigmat calculated by E. von Hoegh (1893), (Fig. 10.14), covering a field of 72° at $f/8$ (afterwards increased to $f/7.7$ and then to $f/6.8$), and almost 90° at $f/22$, forming an excellent universal lens. A number of variants followed, from process lenses covering about 100° at $f/11$

single anastigmat of four cemented glasses, which could be used either separately (field about 50° at a maximum aperture of $f/12.5$) or in pairs, forming either a symmetrical lens at $f/6.3$ or an unsymmetrical lens (Fig. 10.15), at an aperture from $f/7$ to $f/7.7$ (according to the degree of dissymmetry) covering about 45° at full aperture and 80° at $f/25$. This arrangement has since been adopted by the greater number of designers some of whom have pushed the aperture

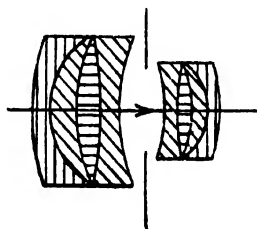


FIG. 10.15. RUDOLPH'S DOUBLE
PROTAR, $f/7.7$

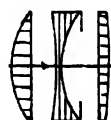


FIG. 10.16. TAYLOR'S COOKE
TRIPLER LENS, $f/6.5$

to the French "Eurygraphe" lens, in which the aperture was enlarged to $f/5$ with the same field of 90°. The number of glasses cemented together in the components was subsequently increased to four, and even five.

The back component of such a lens, when used alone, forms an excellent single anastigmat, perfectly corrected for chromatic and spherical aberrations, but not for coma, and showing, at least at the edges of the field, a little distortion

to $f/5$ and that of the single components to $f/9$. These convertible unsymmetrical anastigmats form the simplest "sets of lenses" giving the photographer a range of three focal lengths in steps, generally in the ratio of 1 : 1.6 : 2 (or 1 : 1.5 : 2.2), the focal length of the complete lens being taken as 1. Care should be taken always to place the single lens, when used by itself, behind the diaphragm, and, when re-assembling the complete lens, to place the

shorter-focus component behind, the longer component being placed in front.

In the early days of photography use was made of convertible lenses to provide a range of focal lengths. In modern practice it is more usual for the photographer to carry a range of lenses of different focal lengths, each one a separately designed unit.

104. Unconvertible Anastigmats. A completely different conception of the anastigmat led H. D. Taylor (1893) to design numerous types of specialized lenses, all consisting of a system of three separated lenses, among which the model shown in Fig. 10.16 is particularly designed for hand cameras, covering 70° at a maximum aperture of $f/6.5$. Among other forms by the

(1898). Originally the maximum aperture was only about $f/10$ for the complete system, but it was extended by Zschokke successively to $f/7.6$ (1903), and then to $f/5.5$ and $f/4.5$, according to the focal length (Fig. 10.18), the field being about 60° at the maximum aperture and 65° at a very small aperture.

The presence of eight glass/air reflecting surfaces has some drawbacks (§§ 58, 59 and 60). The maker of the above type therefore recommends that the lens should preferably be used at full aperture, "because with small stops harmful reflected images may sometimes be formed."

Each of the halves of such a lens can be used separately behind the diaphragm, when the maximum aperture will be $f/10$ to $f/11$.

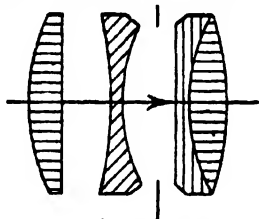


FIG. 10.17. RUDOLPH AND WANDERSLEB'S TESSAR, $f/3.5$

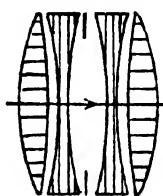


FIG. 10.18. ZSCHOKKE'S CELOR, $f/4.5$



FIG. 10.19. VON HOEGH'S HYPERGON, $f/22$

same designer may be noted a portrait lens at $f/3.5$, covering about 40° , a wide-angle covering 97° at $f/6.5$, and a process lens at $f/8$ ($f/11$ and $f/16$ for the longer focal lengths) covering 55° at full aperture and about 80° at $f/32$.

The advantages of this relatively economical construction, which allows the designer the greatest number of variable factors with the minimum number of lenses, led to the appearance of a number of variants, in most of which, however, one of the single lenses was replaced by a system of two cemented lenses. Such is the case, for example, with the lens designed by Rudolph and E. Wandersleb (1902), of which there are several series. That shown in Fig. 10.17, intended especially for portraiture, covers a field of about 35° at $f/3.5$. Others at $f/4.5$ and $f/6.3$ cover respectively 55° and 65° at full aperture, and 70° with a small stop (about $f/36$).

105. Symmetrical Anastigmats of Separated Lenses. With a view to simplifying the construction of symmetrical convertible anastigmats, many designers have sought to take advantage of the freedom given by combinations of separated lenses. One of the first of this type appears to be that calculated by von Hoegh

106. Wide-angle Lenses. Although such a lens has only a very restricted use, we ought to mention, if only as a curiosity, the wide-angle lens (Fig. 10.19), calculated by von Hoegh in 1900 to cover a flat anastigmatic field of 140° , almost four-tenths of the complete horizon, at an aperture of $f/22$ (actually the full aperture is used

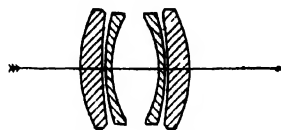


FIG. 10.20. MODERN DALLMEYER WIDE-ANGLE LENS, $f/16$

only for focusing, and a smaller aperture used when the photograph is taken). The correction for astigmatism is only obtained by the use of extremely thin lenses; spherical and chromatic aberrations are not corrected, but the relative aperture is so small, and thus the depth of focus is so large, that these aberrations do not affect the image in practice, and no correction for focus is necessary. When the field used exceeds 110°

the difference of illumination between the centre and the edge is so great that it is necessary to use a star-shaped diaphragm (§ 56) to reduce the illumination at the centre for a considerable proportion of the exposure.

The large angle between the extreme secondary axes, and the fact that the focal length is scarcely one-fifth the diagonal of the plate covered, means that the lens can only be used on a specially-made camera; also it is generally impossible to use a shutter with it.

A more useful wide-angle lens is shown in Fig. 10.20, and is made by Messrs. Dallmeyer. This lens is focused at $f/6.5$, but must be stopped down to $f/16$ for exposure. The angular field at

10.23 (1924), and finally W. Merté's "Biotar" of aperture $f/1.4$ (Fig. 10.24).

108. Variable-power Telephotos. A divergent lens had several times been used for enlarging the image given by an astronomical objective (L. Porro, 1851; Warren de la Rue, 1860), or by a microscope (Foucault and Donné, 1845; Borie and de Tournemine, 1869) when, in 1873, J. Traill Taylor pointed out the importance to photographers of obtaining large pictures of distant objects directly in the camera, by using an objective constructed on the principle of the Galilean telescope (opera glasses) but increasing the separation between the lenses and correcting them specially for this purpose. Such a system,

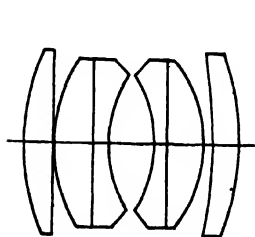


FIG. 10.21. LEE'S OPTIC ANASTIGMAT, $f/2$

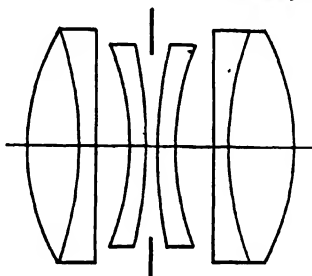


FIG. 10.22. RUDOLPH'S KINOPLASMAT, $f/2$

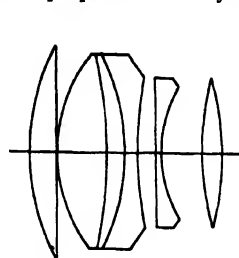


FIG. 10.23. BERTELE'S ERNOSTAR, $f/1.8$

$f/16$ is 90° and increases to 95° at $f/32$. Similar lenses are made by several other manufacturers.

107. High-aperture Objectives. For every type of objective there is a maximum aperture beyond which it is practically impossible to obtain good definition; this limit may sometimes be exceeded by the use of glasses of unorthodox types, but even then the increase in aperture is not striking. The zonal aberrations can be reduced to permissible limits only by using shallow surfaces, so that the refraction of extreme rays is slight for all surfaces. Most high-aperture lenses are related to a portrait lens designed by A. Clark (1889) in the U.S.A., which consisted of two combinations, each of two separated elements, of the type formerly designed by Gauss for telescopes, the lens being nearly symmetrical.

We may mention particularly H. W. Lee's $f/2$ "Optic" (1921), (Fig. 10.21), P. Rudolph's $f/2$ "Kinoplasmast" (Fig. 10.22), in which a small amount of spherical aberration is intentionally allowed, in order to produce "soft" images, A. Klugardt's $f/2$ "Ernostar," subsequently extended to $f/1.8$ by L. Bertele (Fig.

in fact, constitutes an objective the focal length of which can be varied at will between very wide limits by altering the separation between the elements. Also, since the nodal points are thrown forward a great distance in front of the lens, so that the distance between the lens

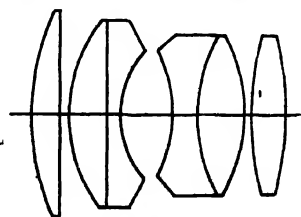


FIG. 10.24. MERTÉ'S BIOTAR, $f/1.4$

and the image is only a small fraction of the focal length, the use of the cumbersome cameras required for normal lenses of great focal length is thus rendered unnecessary. It was only in 1891 that this suggestion was exploited by T. R. Dallmeyer, followed closely by A. Miethe and Steinheil, and then by many other designers.

Consider (Fig. 10.25) a system formed of a convergent lens L_1 of focal length f_1 and a divergent lens L_2 of focal length f_2 , so placed that the back focus f'_1 of the convergent lens falls between it and its (virtual) front focus f_2 . The image of a distant point in the direction R will be formed, in the absence of the divergent lens, at a point r in the focal plane of the front component. This point acts as virtual object to the divergent lens and closer to it than its focus,

$$O = o + [F(s - 1) + f_1]$$

$$I = i - [F(1 - 1/s) + f_2]$$

The ratio s being always greater than (or at least equal to) unity, it is seen that, for a photograph on the same scale, the distance of the object from the telephoto is always greater than it would be with an ordinary lens of the same focal length, and the more so the smaller the focal length of the amplifying negative lens

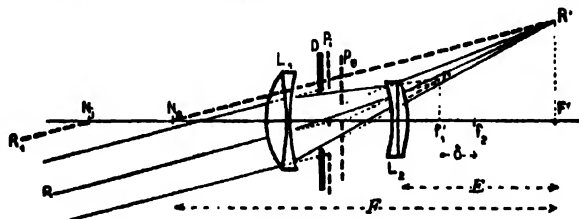


FIG. 10.25. OPTICS OF THE TELEPHOTO LENS

its image R' is real, and magnified in the ratio $F'R'/f_1 r$.

The application of the formulae already quoted in § 70, bearing in mind that the focal length of the divergent lens must have the "minus" sign, gives for the resultant focal length

$$F = \frac{f_1 f_2}{f_1 + f_2 - \epsilon} = \frac{f_1 f_2}{\delta}$$

where ϵ is the separation of the components, δ the optical interval, the distance between the foci $f'_1 f_2$. The formula shows that when δ tends to zero the focal length becomes infinitely great (adjustment of the Galilean telescope for normal sight). Conversely, if the lens L_2 approaches the focal plane of L_1 , there can be no possibility of photographing the image. The optical interval δ can thus take all values between o and $(f_1 - f_2)$, the difference between the two focal lengths.

If the image given by the complete system is magnified m times relative to that which the convergent system alone would have given, the distance E of the divergent lens from the magnified image is

$$E = f_2(m - 1)$$

If, in the case of a telephoto, where $f_1/f_2 = s$, the distances O and I of the object and image respectively from the telephoto and the distances o and i for an ordinary lens of the same focal length giving an image of the same size, are calculated, it is found that—

compared with that of the convergent system. Conversely, the distance from the image to the telephoto is always less than it would be with a lens of the usual construction.

The first telephoto lenses used any ordinary photographic lens as the convergent system, and as amplifier a more or less complex divergent system. The two components were mounted so that the separation could be altered by a rack and pinion, the optical interval δ of the above formulae being marked on a scale on the outer tube, also, usually, the resulting magnification and the corresponding distance of the image.

The first simplification took place in 1896 by the construction of a complete system shown in Fig. 10.26, the divergent system being shown in full lines in the position for a focal length of 4 in., whilst in the position shown by the dotted lines the focal length is about 12 in.

In one or other of these forms the telephoto requires careful handling on account of the very faint image, making focusing difficult when large magnifications are attempted. The use of an optical system with variable separation requires in fact that each of the components should be separately corrected, which is only possible with small apertures. This type of lens must thus be considered as suitable only for special purposes. There is no doubt, however, that it can render very appreciable service.

109. Fixed-focus Telephotos. Very great improvement, at least in the construction of telephoto lenses for general use, was made when

K. Martin (1905) abandoned the variable magnification and made a lens which, in view of its employment on hand cameras, would be more correctly described as a long-focus lens for short-extension cameras. The possibility of compensating the aberrations of each of the components by aberrations of opposite sign in the other, and the removal of the difficulty of centring which arises when two sliding tubes are employed (which must necessarily have a little play) enabled him to obtain an aperture of $f/9$ covering about 35° and giving an image of a quality comparable with that of a good rectilinear. The lens had the advantage that for a focal length of $9\frac{1}{2}$ in. (covering almost the whole of a 9×12 cm plate), the distance from the vertex of the back lens to the plate (practically the same as the distance from the camera front to the plate) was only $5\frac{1}{2}$ in., that is, the equivalent focal length was 1.8 times greater than the back focal distance.¹ The aperture of these lenses was extended later to $f/7$ or $f/7.7$ (by the same designer), with a slightly smaller field, the focal length for the 9×12 cm plate being increased to $10\frac{1}{2}$ in., without increase of camera extension.

The ratio of the equivalent focal length to the back focal length is sometimes called the *power* of *telephoto*, but the use of the term *power* in this connexion is rather unfortunate. Most telephoto

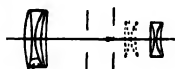


FIG. 10.26 VARIABLE POWER TELEPHOTO

lenses have a "power" of about 2. In England, where this type of lens seems to have reached very great perfection, the aperture has been increased, first to $f/6.8$ and then to $f/3.5$, with a field of almost 35° . Fig. 10.27 shows a lens of $f/4.8$ aperture by H. W. Lee (1922). These lenses have been made up to now for use on hand cameras of size not exceeding 7×5 in. Recent types give an image comparable with that given by the best modern lenses of normal construction.

"Reversed" telephotos, that is, lenses in which the back focal length is greater than the

equivalent focal length, have been used in cameras where it is desired to insert some system, such as the rotating prism in high-speed cine cameras, and the beam splitters in three-colour cameras.

110. Other Lenses of Variable Focal Length. On many amateur cameras one of the elements of the lens may be displayed relatively to the others by rotating the front of the lens mount. This produces a change of focal length and a displacement of the back nodal point in order

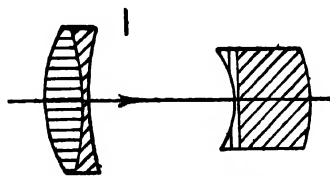


FIG. 10.27. FIXED-FOCUS TELEPHOTO, $f/4.8$ (LEE)

to focus on objects at different distances. This was first effected by moving the front element of a triplet (H. D. Taylor, 1902), and later by moving the front element of a four-element lens (C. W. Frederick, 1920). In other lenses the back element has been moved (W. Gehrke, 1930). A very slight change in the separation of the elements is sufficient in many cases to produce an appreciable change in the focal length of the system, and thus the design of the camera may be considerably simplified. This method is not applicable to high aperture lenses, in which the performance would suffer appreciably from a change in separations.

111. A similar device is used to obtain certain effects in cinematography. In Warmisham's "Varo" (1932), the focal length may have any value between $1\frac{1}{2}$ and 5 in. without changing the position of focus for distant objects (focusing for short distance is effected by the use of supplementary lenses). As the focal length is progressively increased (by means of a lever which changes the position of one part of the system) the scale of the image also increases, and the field of view decreases. This gives the impression, on projection of the film, that the camera must have been moved smoothly along its own axis towards the object. A lens which does not suffer from the defect inherent in Warmisham's design, namely that the relative aperture changes with the focal length, was designed by F. G. Back (1946) and given the name "Zoomar." When used on 16-mm film

¹ The back focal distance is the separation between the nearest part of the back surface of the lens and the focal plane.

this lens is capable of a change in focal length from 17 mm, where it acts as a wide-angle lens, to 53 mm, where it acts as a telephoto lens. By changing the front lens, the range of equivalent focal length can be shifted from 35 to 106 mm without change of image position or light transmission.

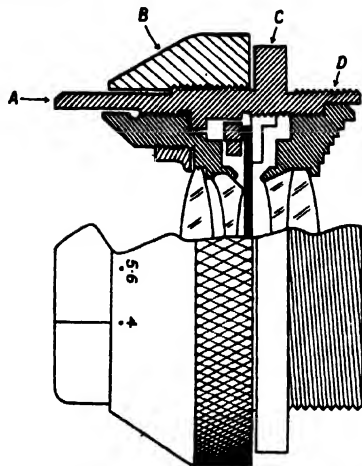


FIG. 10.28. SECTION OF MODERN LENS AND IRIS DIAPHRAGM

A = hood. B = diaphragm. C = flange. D = thread.

112. Different Types of Lens Mounts. Several types of mounts are employed for photographic lenses, according to the use to which they are to be put.

For cameras which are always used with a tripod (studio and field cameras), where there is no limit to the projection of the mount, a *normal mount* (Fig. 10.28), the simplest type of all, is usually fitted, the flange being attached to the rear of the lens mount, giving free access to the diaphragm. On hand cameras, where bulk has to be reduced, a *sunk mount* is often preferable, the flange being on the front part of the mount, which is thus sunk inside the camera in order to make use of the space corresponding to the thickness of the bellows (when closed). The diaphragm is then operated from the front by a cylindrical lining between the exterior mount and the actual body of the lens.

When the camera is not fitted with any adjustment for focus a *helical focusing mount* is employed, with the flange in front and comprising, beside the tube actuating the iris, three concentric tubes. Two studs fixed on opposite sides of the inner tube engage in helical slots in

the intermediate tube and in slots in the outer tube parallel to the axis. A rotation of the intermediate tube by means of a ring working over a scale of distances causes the lens to move forward or backward without rotation.

Finally, for use with between-lens shutters (§ 138), the mount is reduced to two or three cells in which the lenses are bevelled or held in with clamp rings, these cells being screwed into the female screws provided at either end of the shutter. It cannot be too strongly recommended that the mounting of a lens on a between-lens shutter should be entrusted to the maker of the lens, so that there should be no alteration in the separation of the elements of the lens to spoil its qualities. Makers generally engrave their trade-mark, serial number, and lens characteristics on the front only. The back cells of lenses of the same series and mean focal length are not usually optically interchangeable, but as they are mechanically interchangeable some manufacturers avoid confusion by engraving on the back cell at least the number of the lens. The female screws of the cells can be used for inserting filters, supplementary lenses, etc. When the lens is focused for different distances

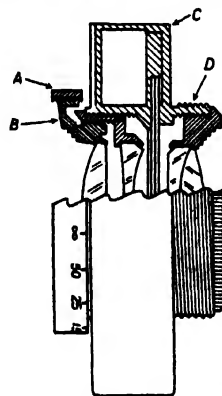


FIG. 10.29. SECTION OF MODERN LENS MOUNTED IN SHUTTER WITH FRONT-CELL FOCUSING

A = focusing scale. B = focusing mount. C = shutter. D = thread.

by adjusting the position of the front element (§ 110) a mount of the type shown in Fig. 10.29 is used.

The mounts of old lenses always had a *hood* of very great projection, either integral with the front cell or detachable, but some modern lenses do not carry such a hood, and it is often necessary to use an auxiliary hood (§ 124).

Attachment of the lens to the camera may be

by means of a screw thread, or by a bayonet type fitting.

The materials used for lens mounts are generally brass, or the light aluminium alloys; pure aluminium, which was used for some time, had the drawback that the threads rapidly wore out. When a lens of long focal length is likely to undergo large changes of temperature (aerial photography at high altitudes) it is well to restrict the expansion and contraction of the mount by using the *invar* steels, or to adopt a compensating device like those frequently used on clock pendulums. In every case where the lens may be used for the copying of originals under glass, it is desirable that the mount should be finished in mat black lacquer so as to minimize reflection.

A necessary accessory is the cap, made of leather, or metal with a velvet lining. The lens being considered to remain on the camera, only the front lens is then exposed to shocks, and only one cap is usually provided. When several lenses are carried with one camera, it is well to fit a cap on the back cell as well. The lenses on cameras exposed in dealers' shop windows might very well be provided with glass-fronted caps which would keep out the dust but leave the maker's name visible.

113. Choice of a Lens. The descriptions previously given (§ 111) form sufficient guide to the choice of a lens required for a special purpose, so that we shall now consider only the case of the modest amateur desiring to attempt the most varied work with the greatest possibility of success, with only one lens.

The single lens is usually only found on small cameras for beginners. In very good light, moving objects may be photographed, but the small aperture ($f/16$ to $f/11$) obviously will not allow of instantaneous photography in poor light. Even cheap box cameras, however, are now provided with flash contacts to enable a flash bulb to be fired simultaneously with the shutter, which extends the use of these cameras to conditions which would previously be unfavourable.

Most modern cameras of the better class are fitted with anastigmats and have apertures from $f/6.3$ to $f/4.5$. Many have apertures larger than $f/2.5$. High shutter speeds are then possible, enabling even very rapid movement to be photographed. In other words, the principal advantage of the anastigmat, thanks to its greater speed, is to extend the lighting conditions under which it is possible to photograph moving objects.

Regard must, however, be paid to the fact that the employment of larger apertures reduces the depth of field, the estimation of the distance on which to focus becoming much more difficult in proportion as the aperture is increased. Hence it may be considered that apertures in the neighbourhood of $f/3.5$ will be only rarely used in outdoor photography unless it is proposed to specialize in the photography of objects in very rapid movement requiring exposures of the order of $1/1,000$ th second, or in colour photography.

The property of the anastigmat of covering a larger field so that a shorter focus lens can be

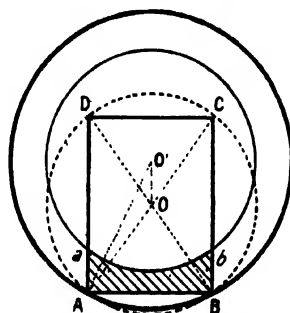


FIG. 10.30. PLATE SIZE IN RELATION TO LENS FIELD

used for the same plate, thus reducing the size of the camera, is generally considered an advantage. Although this is so for some kinds of photography, it is difficult to avoid regarding it as a drawback from the point of view of pictorial photography, the smaller scale of the image tempting the photographer to approach too near to his subject.

If the camera allows sufficient extension, the employment of one of the components of a convertible anastigmat is to be preferred, the complete lens being then used for subjects with movement, and either of the components for landscape photography.

114. Choice of Focal Length. The necessity that often arises for displacing the lens (§ 151) normal to its own axis so as to raise or lower the horizon, especially for the photography of high buildings, while keeping the optic axis of the lens horizontal, requires the choice of a lens such that the diameter of the field covered sharply should considerably exceed the diagonal of the rectangle defining the image, at least when stopped down.

PHOTOGRAPHY: THEORY AND PRACTICE

DIAMETER OF THE SHARP IMAGE (THE FOCAL LENGTH BEING TAKEN AS UNITY)

Angle of field	Diameter of image	Angle of field	Diameter of image	Angle of field	Diameter of image
10°	0.17	55°	1.04	100°	2.38
15°	0.26	60°	1.15	105°	2.61
20°	0.35	65°	1.27	110°	2.86
25°	0.44	70°	1.40	115°	3.14
30°	0.54	75°	1.54	120°	3.46
35°	0.63	80°	1.68	125°	3.84
40°	0.73	85°	1.84	130°	4.28
45°	0.83	90°	2.00	135°	4.84
50°	0.93	95°	2.18	140°	5.50

IMAGE SIZES (NOMINAL) AND THEIR DIAGONALS

Dimensions	Diagonal in inches	Dimensions	Diagonal in inches	Dimensions	Diagonal in inches
1.8 × 2.4 cm.	1.18	8.2 × 10.8 (4½" × 3½")	5.28	18 × 24	11.82
2.4 × 3.6	1.78	9 × 12	5.91	20.3 × 25.4 (10" × 8")	12.81
3 × 4	1.97	10.1 × 12.7 (5" × 4")	6.38	21 × 27	13.48
4 × 4	2.24	9 × 14	6.54	24 × 30	15.13
4 × 5	2.52	10 × 15	7.09	25.4 × 30.4 (12" × 10")	15.60
4.5 × 6	2.96	11 × 15	7.33	27 × 33	16.78
6 × 6	3.35	12 × 16.5 (6½" × 4½")	8.04	30.4 × 38.1 (15" × 12")	19.19
6 × 7	3.78	12.7 × 17.8 (7" × 5")	8.59	30 × 40	19.70
6.4 × 8.9 (3½" × 2½")	4.33	13 × 18	8.75	40 × 50	25.22
6.5 × 9	4.37	15 × 21	10.17	50 × 60	30.77
8 × 9	4.73	16.5 × 21.5 (8½" × 6½")	10.69		

If we consider, for example, a plate 9×12 cm (Fig. 10.30), of which the diagonal is 6 in., a field of 6 in. diameter would cover it if the lens were always centred on the plate, i.e. if its optic axis always met the plate in the point O , the intersection of the diagonals of the rectangle $ABCD$. But if the lens is to be decentred 1.2 in. parallel to the long sides, so that it comes opposite O' , the lens considered above would no longer cover the shaded area $AabB$, and in order then to cover the plate, the field covered sharply should be equal to the circle with O' as centre and radius $O'A$, i.e. a diameter of 8 in., which would cover a plate $6\frac{1}{2} \times 4\frac{1}{2}$ in. in the absence of decentring. A margin of a few millimetres (about one-eighth of an inch), corresponding to the rebate on the dark slide to hold the plate, should, to be exact, be deducted from the normal plate size.

Lenses being generally characterized by the angle of field sharply covered (angle between the secondary axes to the two extremities of the diameter of the circle of the sharp image, or to

the two extremities of the diagonals of the rectangle which can be inscribed in this circle), the two tables given above indicate, in the first, the factor by which the focal length should be multiplied to obtain the diameter of the sharp image when the angle of field is known (viz., twice the tangent of the semi-angle of field); and in the second, the lengths of the diagonals corresponding to the different plate sizes. In this second table the sizes common on the European continent are indicated by heavy type; those in use in England and America by *italics*, with the sizes in inches in brackets.

This table does not include the stereoscopic plate sizes corresponding to the size of two single pictures.

The eye includes an angle of only 50° , so it is recommended (if the photograph is to be viewed from its normal viewpoint) that the use of a larger angle of view should be avoided, except for record work, where a wide angle can be used. This amounts to saying that the focal length, at least in landscape photography, ought

to be at least equal to the diagonal of the plate. In fact, the bad habit has been established, either for economical reasons or by an innate tendency to include in a photograph as much as possible, even if a great part has afterwards to be sacrificed in the print to unify the composition, of choosing almost invariably a lens of the shortest focal length in the maker's catalogue which will cover the plate. This is the more often done as some catalogues purposely print the expression "recommended for such-and-such a size," instead of the more desirable "able to cover, at the maximum, such-and-such a size." It is thus that many cameras are fitted with lenses of which the focal length is scarcely greater than the longer side of the plate, except in the case of large-aperture lenses, which always have a smaller angle of field.

There is obviously no disadvantage in employing a lens covering a larger angle of view, if only a part of this angle is used in the photograph, but in this case care must be taken that light reflected from the sides of the camera does not fog the image. The detachable lens hood is here called for.

Particular considerations limit the choice of focal length of studio portrait lenses. On the one hand it is very desirable, in order to avoid foreshortening and exaggeration of near parts, to place the camera at least 12 ft away from the sitter for a head and shoulders or half-length portrait, and at least 20 ft for full-lengths or groups. On the other hand, it is obviously necessary to take into account the dimensions of the studio and the distance available between sitter and camera, since the sitter cannot be placed against the wall and the operator must have room behind the camera for focusing and manipulating the dark slides, both of which requirements take away at least 6 ft from the actual length of the studio. Finally, in industrial towns, where dust is plentiful in the air, the light diffused by the dust (when the space between the camera and sitter is illuminated) will produce a slight haze over the image if the distance between sitter and camera exceeds about 40 ft.

Allowing a mean height of 5 ft 5 in. for an adult, and that the head is about one-seventh the height, i.e. 9-9½ in., it is easy to find, by using the rules formulated in § 64, the distance the sitter must be away from the lens in order to obtain an image of any desired size, or, inversely, to determine what is the greatest focal length which, in the space available, will allow of a

given degree of reduction. For a small print (head about 0.8 in., or full length about 2½ in. on 3½ × 2½ in. paper), a lens of 11 in. focal length will require a distance of 23 ft, so that the studio must be about 30 ft long. For larger portraits (a head measuring about 1.6 in. or a full-length figure 4 in. on paper 5 × 4 in.), or for post cards (5½ × 3½ in.), the same length of studio would allow the use of a lens of 21 in. focal length for head and shoulders, or a lens of 14½ in. focal length for a full-length portrait, these focal lengths being the shortest which permit the camera to be placed sufficiently far from the subject to produce an agreeable perspective.

The table below indicates the distances between the sensitive plate and the subject necessary to obtain the image of a head or of a full-length figure, of given dimensions, taking the focal length (f) as unit of distance—

HEAD (LENGTH 9½ IN.) REDUCED TO				
0.8 in.	1.6 in.	2.4 in.	3.2 in.	4.8 in.
14.1f	8.2f	6.25f	5.33f	4.5f

FIGURE (LENGTH 5 FT 5 IN.) REDUCED TO				
2.8 in.	4 in.	6 in.	8 in.	10 in.
25.6f	18.6f	13.1f	10.4f	8.75f

The only calculation to be done is to multiply the number given above by the focal length of the lens to be used.

It is no good trying to use a large aperture with lenses of very great focal length, since the depth of field would be insufficient even for a profile portrait; it would constantly be necessary to use the lens at a much smaller aperture. $f/3.5$ can be taken as a practical limit for a lens of 12 in. focal length, $f/5.6$ for 20 in., and $f/8$ for 30 in. (See § 80 on "Factors Affecting the Depth of Field.")

115. Practical Testing of Lenses. The practical testing of a lens should be carried out under conditions as similar as possible to those in which it will be used; it would be as absurd to test on a distant subject a lens intended for process work as to test on a close-up subject a lens to be used for aerial photography. Similarly, if the lens is to be used normally with fast, coarse-grain film, it could be misleading to test it with a fine-grain emulsion. The contrast of the test object is also of importance; it should not be much greater or much less than the average contrast of the normal subject matter.

As far as possible, the test of a lens should be carried out on a camera of larger size than the maximum field of sharp definition expected,

choosing preferably a camera known to be in perfect working condition, in order to run no risk of attributing to the lens any constructional faults of the apparatus, such as lack of register between the positions of the ground glass and the sensitive emulsion which is substituted for it after focusing.

The first test to carry out is that for achromatism. For this, according to the intended normal use of the lens, either a page of a newspaper stretched on a wall, or a brick wall with bold lines, should be used as a test object, both being photographed obliquely from an angle of about 45°. Focusing having been done very carefully on an easily identifiable vertical line, a photograph is taken at the full aperture of the lens, preferably on a slow plate or lantern plate, so that there will be no trouble from excessive graininess of the image. If achromatism is exactly corrected, and if the dark slide is in register with the focusing screen, the sharpest line on the photograph will be that focused on.

To test for colour correction, photograph near the limit of the field a transparent line on an opaque ground (made for example by a scratch on a uniformly fogged plate) behind which are placed three small pieces of gelatine filter, of the type used for three-colour separations. Any lack of alignment in the negative will indicate a difference in scale between the images formed by the different colours.

To find the extent of the field of good definition without using a larger camera, it will be necessary to decentre the lens as much as possible, noting the amount, so that it will be easy to identify the position of the centre of the field on the photograph. It must be assumed that the definition is symmetrical (which will be the case with a centred system), unless the test is repeated with the decentring in the opposite direction or after unscrewing the lens half a turn in the flange (and readjusting the focus).

To test a process lens, a number of good proofs from half-tone blocks spread over the field embraced by the lens may preferably be used as a test object and photographed the same size or slightly smaller. To test a portrait lens, papers printed in large type are pinned against the wall of the studio and photographed at about 16 ft distance. To test a landscape or architectural lens, choose a large façade in brickwork with bold joints as test object, and photograph at a distance of about 60 ft, and as far as possible with the lens axis at right angles to the wall. Each of these tests should be carried

out at maximum aperture, and at a number of smaller apertures, in order to compare the definition at different apertures.

When comparing different lenses, care should be taken to make the comparison at equal relative apertures and at equal exposures on identical plates, which should be immediately developed together. If each of the lenses is mounted on a shutter, do not trust to the speeds marked on the shutters, which may not be accurate. It should be emphasized that unless all conditions are strictly controlled, it is impossible to arrive at an accurate comparison of the performance of different lenses. Moreover, one should not rely on the comparison between a single example of each of two different types of lens if one wishes to decide which is the better type. Differences in performance from lens to lens made by the same manufacturer may be greater than the average difference between two types.

116. Preservation and Care of Lenses. When not in use, lenses should be kept in a clean, dry place, in a dust-tight sheath-case or at least with caps on both ends. Where the lens has cemented components, which are liable to exposure to excessive heat (particularly if occasionally employed on an enlarger using artificial light), shield it from the source of light by an opaque screen of card or metal, except when actually focusing or exposing.

Strict cleanliness of all surfaces is a necessary condition for obtaining clear images. A lens of which the surfaces diffuse the light either through condensation of steam or adherent dust, or grease marks due to contact with the fingers, will form a *halo* round all the high-lights, and more or less completely veil the shadows.

Meticulous care is necessary in cleaning the lens surfaces. In the first place, atmospheric dust contains, among other things, numerous microscopic grains of sand, liable to scratch window or plate glass. Now optical glasses are considerably softer than common kinds, so that the rubbing of these grains on the surfaces of the lens, in the course of unskilful cleaning, causes the innumerable scratches seen on many lenses after some years' service. This slight abrasion will considerably impair the qualities of the lens.

In cleaning, all substances which are likely to deposit grease on the lens (such as chamois leather) should be avoided. Silk electrifies the glass and causes more dust to adhere. Linen cloth, taken from old linen garments, is very suitable for cleaning if recently washed and kept

away from dust (in a well-closed metal box). Special lens-cleaning tissue is readily available and is cheap enough for a sheet to be discarded when once used.

Before cleaning, the surfaces should be dusted without applying pressure to the glass, e.g. with a very soft dry brush, kept for this purpose in a dust-proof case, and washed from time to time in denatured alcohol and immediately hung up to dry in filter paper.

The inner surfaces will not require dusting and cleaning so often as the outer surfaces, lens mounts with iris diaphragms being practically dust proof. Never unscrew at the same time both the front and back components, nor the components of a stereoscopic pair, in order to avoid the risk of interchanging them.

After dusting and dry cleaning, see that the surfaces are perfectly clean, which is best done in a room lighted by a single lamp, not too bright, looking at the lens held in a position slightly off the line joining the lamp and eye. If a dirty mark is seen, moisten it with a little soapy water

and rub gently. If this does not remove it, moisten with a little denatured alcohol, taking care that none of it gets between the lens and its cell, as it might dissolve the Canada balsam used for cementing: after a few seconds, wipe dry.

In any case never try to polish the surfaces of a lens with a powder (chalk or rouge) or polishing paste, for the slightest wearing away of the glass which this polishing would produce would be sufficient to deform the surface and impair the quality of the lens. Never apply to the glass any alkaline solution, however weak, as optical glasses are extremely sensitive to action by chemical reagents and even to damp.

Every time the lens is taken to pieces, be careful to wipe the inside of the mount, and see that the mat varnish has not peeled off at any place, showing bare metal which would reflect any light falling on it. If there is a bare spot to be seen, apply a little black mat optical varnish.

To prevent subsequent steaming of the inside surfaces it is advisable to assemble the lens in a very dry place or close to a fire.

CHAPTER XI

LENS ACCESSORIES: SUPPLEMENTARY LENSES, LIGHT-FILTERS, POLARIZERS, PRISMS AND MIRRORS, LENS HOODS, SKY SHADES

117. Supplementary Lenses (Magnifiers). Cameras of the fixed-focus type will produce a sharply defined image of the object only if it is at a sufficient distance from the camera, the picture being then on a small scale. In order to increase the usefulness of such a camera it is possible to mount positive supplementary lenses or magnifiers in front of the lens.

It must be emphasized in the first place that such magnifiers, and also the negative supplementary lenses referred to later, must be correctly centred with the camera lens. This excludes the use of all universal spring mounts, which can be adapted to filters or hoods of different diameters. The supplementary lens should be mounted in a small tube, which is either screwed into the inner thread of the lens hood or on to the outer mounting of the lens, or it can be simply slipped tightly over the barrel of the lens.

For example, suppose that it is desired to photograph a subject at 1.50 m^1 (5 ft) with a camera which is focused on infinity. It will then be sufficient to place a converging lens of 1.50 m (5 ft) focal length in front of the camera lens, that is a positive lens of 0.67 diopters. The subject will then be situated in the focal plane of such a supplementary lens. Rays of light coming from any point on the object to the magnifier are then transmitted from the latter and arrive on the camera lens as a beam of parallel light, i.e. in the form of rays coming from a very distant point.² It will thus be seen that if a set of supplementary lenses with properly chosen focal lengths is available, a fixed-focus camera can be used to photograph objects at all distances which are less than the minimum distance fixed by the limits of the camera. A point to remember is that each optical accessory increases the amount of stray

light due to successive reflections from the glass surfaces.

With a camera which has a focusing adjustment but has an extension that is too short to allow a very near object to be photographed, the use of suitably chosen supplementary lenses will further extend its scope. If, for example, the camera cannot be focused on a distance less than 2 m ($6\frac{1}{2} \text{ ft}$) and it is desired to photograph an object placed at a distance of 1.50 m (5 ft), the camera should be set at 2 m and a supplementary lens fixed on the front of the camera lens. This magnifying lens should have a power equal to the difference of the proximity ($= \frac{1}{\text{distance}}$) of the object and the point on which the camera is focused, i.e. in this case

$$\frac{1}{1.50} - \frac{1}{2} = 0.67 - 0.50 = 0.17 \text{ diopters}$$

This corresponds with a focal length of $\frac{1}{0.17} = 6 \text{ metres}$ ($19\frac{1}{2} \text{ ft}$).

With subsequent adjustment of the focus on a convenient distance, it is possible to use any magnifier whose focal length comes within the limit thus calculated and that corresponding to the use of the camera focused on infinity.

Due regard must, however, be paid to the fact that the supplementary lenses usually employed are uncorrected, and their use with a camera lens introduces aberrations into the resulting image (chromatic, spherical, astigmatic, etc.), which are more pronounced the stronger the additional lens. For this reason, if there is a choice between two supplementary lenses of different focal lengths, it is advisable to choose the one of the greater focal length, and to focus the camera accordingly.

Another fact must be taken into account, viz. that the focal length of the combination is smaller than that of the camera lens itself, so that the latter will have a larger effective aperture than that indicated by the marking on the diaphragm. For example, suppose that the lens has a focal length of 15 cm (6 in.), and that a magnifier of 1 metre (3 ft) focal length is being used (6.7 and 1 diopters respectively), the

¹ The optical calculations in this chapter have been left in metres since the power of lenses commonly supplied in England as supplementaries is usually specified in diopters, the reciprocal of the focal length in metres.

² In practice, if a fixed-focus camera has the focus set on the hyperfocal distance instead of infinity, the object should be arranged slightly on the far side of the focal plane of the supplementary lens.

resulting focal length will then be $\frac{1}{7.7} = 13$ cm.

(§ 70). Thus the effective aperture of each stop will be increased in the ratio of 13 to 15, that is, multiplied by 1.15, so that, taking into account the losses by reflection at two additional surfaces (about 10 per cent), the effective speed of the lens will be increased by about 20 per cent. When using a less powerful supplementary lens, the gain in speed would be considerably less, and the gain may easily disappear or be converted into a loss by the reduction of light due to surface reflections. Moreover, the increase in speed is generally illusory, for if the image is required as sharp as that obtained when the camera lens is used alone, it is necessary to use a smaller aperture.

This reduction of the focal length also brings about, *ipso facto*, an increase in the depth of field, which at the same time is further increased since an incompletely corrected optical system has always a slightly greater depth of field (§ 85).

Positive supplementary lenses, while useful for record work, have unfortunately been used for portraiture, and as if the majority of photographers had not already a marked tendency to place their models too near the camera, the use of such supplementary lenses has been popularized under the name of "*portrait attachments*." It cannot be too strongly emphasized that a portrait taken at too close a range is not far removed from a caricature of the sitter.

118. *Tele-attachments*. In the same way that the focal length can be reduced by using converging supplementary lenses, so it can be increased by the addition of a diverging lens (R. Viney, 1897). The use of such a lens is of great advantage in landscape or portrait photography when it is not possible to separate the lens components. The increase in focal length causes a reduction of the angle of view. The softening of the definition resulting from the aberrations of the uncorrected lens, and the greater homogeneity of the image in the various planes, reduce what might be called, from an artistic point of view, the defects of a too well corrected lens.

It is possible to calculate the approximate value of the focal length (within 5 per cent) by assuming the power of the combined system to be equal to the difference between the powers of the camera lens and the supplementary lens. If a lens of 15 cm (6 in.) focal length, or 6.7 diopters, is coupled with a diverging lens of

50 cm (20 in.) focal length, or 2 diopters, the power of the combination will be approximately 4.7 diopters, i.e. a focal length of about 21.5 cm (8½ in.). In order to avoid excessive aberrations, and since an adjustment in focus is needed as when using an anachromatic lens, the power of the diverging attachment must not be as much as half that of the camera lens. If, on the other hand, a supplementary lens of very low power is employed, its effect is very nearly negligible. In practice, the focal length of a diverging lens attachment should not be more than double nor less than a quarter of the camera lens with which it is being used.

Diverging meniscus lenses are to be preferred to cheap bi-concave spectacle lenses, and are used with the concave side towards the camera lens.

119. *Light-filters*. The optical properties only of light filters will be considered here. Light filters consist of a coloured disc of plate glass with plane and parallel faces or of a sheet of coloured gelatine which is either used as such or cemented between thin, flawless plate glass, or thick optically worked pieces of glass.

With the exception of the plain gelatine filters, which are too thin to modify the rays of light to any appreciable extent, any filter which is placed in front of or behind a camera lens alters the position of the sharp image, and introduces various aberrations into it.

If a pencil of light is made to converge at a point P by some optical system (Fig. 11.1), and a thick sheet of glass L , or some other transparent material with plane and parallel faces is interposed, it is easy to show that the image is displaced from P to P' , its distance from the optical system being *increased*. If the inclination of the pencil is relatively small on the face of the sheet, the point P' is situated on the perpendicular drawn through P in a direction common to the two effective faces of the plate (L), and, if the latter is of glass, the displacement PP' of the image is approximately equal to a third of the thickness of the filter. A plate of thickness l of a substance of which the refractive index is n , is equivalent, from the point of view of the passage of rays of light, to a thickness of air equal to l/n ; the difference between its actual thickness l and its effective thickness l/n , i.e. $l(n-1)$, represents the displacement of the sharp image, measured in the direction of the propagation of light. The glass used in the construction of filters (crown or plate glass) has a refractive index of about 1.5 so that the displacement of the image is about $l/3$.

If the filter is placed in such a way that the optic axis of the lens is perpendicular to its face, this being the necessary condition for the whole to constitute a centred system, the effect of the filter will be the same for every pencil of light. It will be sufficient to increase the distance between the plate and the lens by a third of the thickness of the filter, in order that everything may be in practically the same condition as before the introduction of the filter. If, on the contrary, the filter is not perpendicular to the lens axis, the differences of obliquity of pencils of light equally inclined to the optic axis cause deformation of the image. This may

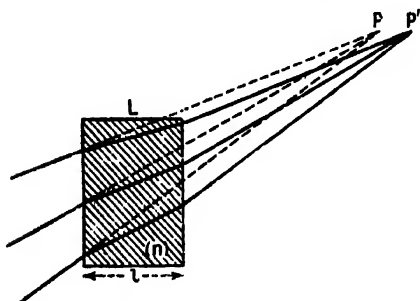


FIG. II.1. EFFECT OF LIGHT-FILTER ON FOCUS

not be very considerable, it is true, but it would be particularly noticeable in negatives which had been taken through a badly placed filter, and which were required to give exactly super-imposable images (three-colour work).

When the filter is placed between the subject and the lens, it is sufficient to consider the point P' (Fig. II.1) as one of the points on the object, and it will be clear that, after passing through the filter, the rays will seem to come from the virtual point P , which is nearer to the lens than the actual point on the object P' . Thus, the whole object is brought virtually nearer the objective, and the amount of displacement is equal to about one-third of the thickness of the filter.

The image is formed *further* from the lens than before interposition of the filter. If a camera is focused on an object and the object is reproduced on a scale of $1/m$, the increase in extension of the camera will be equal to the thickness of the filter divided by $3m^2$, a displacement which is negligible even for the thickest screens, when the object being photographed is not very near the lens. It is easy to show that the displacement of the image in this case is strictly

equal to $l/(3m^2 + \frac{lm}{f})$. The second term in the denominator is negligible compared with the first if m is appreciably greater than unity (reduction) and if the thickness l is only a small fraction of the focal length f .

In addition to the displacement of the image resulting from the interposition of a filter, the image is affected even if the filter is optically perfect; these various aberrations, however, are fortunately small enough to have practically no disturbing effect. In the case of thick filters mounted in front of a wide-angle objective, the chromatic aberrations may become of considerable importance, especially if the object is to superimpose the negatives taken through variously coloured filters; an appreciable barrel-shaped distortion is noticeable if the filter is between the lens and the image, while it is crescent-shaped if the filter is between the lens and the subject, slight curvature of the field occurring in both cases. For an equal thickness of filter, these aberrations are greater when the filter is on the same side of the lens as the nearer of the two conjugate planes. This is one of the reasons why filters are usually mounted in front of the lens for portrait or landscape photography.

Cheap commercial filters are mounted between ordinary plate glass, the faces of which are usually neither plane nor parallel, and if used instead of optically perfect filters it will mean that the image may suffer considerably in quality, especially when such filters are used with a lens of long focal length and relatively large aperture. When this is the case, plain gelatine screens are to be preferred to filters of mediocre quality.

If the filter faces are parallel only one image is seen when looking at the reflection on the filter of distant objects, the line of vision being preferably glancing along the surface of the filter. If the faces are not parallel two separate reflected images will be seen.

120. The Best Position for Mounting Light-filters. A misconception which is frequently entertained is to suppose that the efficiency of a light-filter can vary according to its position in the beam of light. A filter always absorbs a definite proportion of each incident radiation, whatever the intensity of the light or its area of cross-section at the point where the filter is placed. For instance, if a light-filter, used near the lens, cuts the beam of incident light at a cross-section twenty times less than would a filter placed in contact with the sensitive plate,

and if the quantity of light incident on the filter is therefore twenty times greater, from each of these radiations which pass through it, it will absorb a quantity twenty times greater per square centimetre. However, the total quantity of the whole beam of light absorbed will be the same, and the selective effect will be exactly the same.

A light-filter may be placed (a) between the source of light and the object to be photographed; (b) between the object and the lens of the camera, and in this case it is usually mounted on the lens; (c) between the components of the camera lens; (d) between the lens and the sensitive plate, adjacent to the lens; (e) in front of the sensitive plate, almost in contact with it.

Position (a), generally used in micrography, has sometimes been used for the three-colour reproduction of colour transparencies. But it is difficult to imagine a studio with all the lights entirely covered by light-filters.

Position (c) should be rejected on principle, except when using gelatine screens of negligible thickness, which can be placed against the iris diaphragm after unscrewing one of the components of the objective. Every filter of appreciable thickness, being equivalent to two-thirds of its thickness of air, would produce very nearly the same effect as if the separation of the components of the lens had been reduced by a third of the thickness of the filter. This would seriously interfere with the definition unless the filter formed an integral part of the lens and was placed in position, with due regard to its effect, by the lens designer.

The fact that a filter, when used close to the sensitive plate, can be of mediocre optical quality without disadvantage has been put forward in favour of position (e). Unfortunately, any local defect in such a screen manifests itself on the image as a spot. Further, a "focal-plane filter" of indifferent quality is at least as expensive and immeasurably less workable than a "lens filter" of satisfactory quality, or, better still, a plain gelatine screen.

Usually the only two positions which must be considered are, therefore, those in front of (b) or behind (d) the lens of the camera.

In the circumstances usually occurring in practice, a filter placed in front of the lens does not alter the focus, which is a very appreciable advantage in the case of cameras with which the focusing is done on a graduated scale. On all other cameras this position of the filter lends itself most readily to taking on and off

with the minimum of trouble. The filter can either be mounted in a ring, which is fitted over the lens like a cap, or provided with threads which allow it to be screwed into the lens hood. In short, in all cases where the object to be photographed is more than twice the focal length distant from the objective, the filter in front of the lens, in the case of thick filters, is least likely to introduce disturbing aberrations into the image. In commercial photographic work which calls for the use of a set of several light-filters, instead of fitting each filter in a separate metal mount, an adaptor is placed in front of or behind the lens of the camera, into which any filter can be fixed by means of a movable holder. If the lens is fitted with Waterhouse stops it should be possible to introduce into the opening for the stops a gelatine filter which has been slipped between two thicknesses of thin black card, forming a diaphragm.

121. Care of Light-filters. When not in use, all light-filters should be protected from the action of light, since the dyes with which they are made are sometimes affected by its prolonged action, and changes in their spectral absorption power may be caused in time.

When cleaning filters cemented between plate glass, the same precautions should be observed as when cleaning photographic lenses. Water should never be allowed to come into contact with the edges, since any wetting of the gelatine film would cause the latter to swell and might cause deformation of the filter and separation of the glasses.

Plain gelatine filters should never be handled except by their edges or between fine tissue paper; any contact with the fingers invariably leaves fingermarks which cannot be removed and which seriously impair the definition. After being cut out, gelatine filters can be protected by dipping in a celluloid varnish. The filter should be held by a corner or by a point at the circular edge. After draining it should be put to dry. The operation must then be repeated, the filter being held by the opposite corner or by the point at the edge opposite to the first one. These screens must be protected from heat and damp, and when not in use should be kept between the leaves of a small notebook of white paper. When it is desired to cut out a circle of gelatine filter for fitting into a lens, breakage of the film can best be avoided by cutting it out between two pieces of strong paper, one of which has the circle to be cut out marked on it. As gelatine screens continually undergo

slight expansions and contractions according to the humidity, they should never be fitted into any kind of rigid frame. Lastly, gelatine filters should never be kept between plate glass unless suitably cemented on both sides, e.g. Canada balsam (solution in xylene). In this way multiplicity of reflecting surfaces and risks of tearing the gelatine will be avoided.

122. Polarizers. In normal light radiation, the light waves vibrate in all directions, perpendicular to the direction of propagation (§ 2). Various conditions can polarize light, that is, preserve only the vibrations parallel to a given plane, called the plane of polarization. For instance, the light diffused by a blue sky is polarized, and the clearer the sky the more complete the polarization. Light reflected from a non-metallic surface is polarized, the polarization being complete when the reflected rays are perpendicular to the refracted ones (reflection under an angle of 35° with the reflecting surface in the cases of glasses with a refractive index of 1.5). If the surface is transparent the refracted light is partly polarized, and it is then possible to decrease the proportion of non-polarized light by causing the light to pass through several thin plates in a stack. The light that has passed at the appropriate angle through a suitable assembly of double-refracting colourless crystals (Nicol or Glazebrook prisms, made of Iceland spar) is totally polarized. Light that has passed a double-reflecting crystalline dichroic plate (Tourmaline, Herapathite or quinine iodosulphate) or a film holding in suspension a multitude of double-refracting, dichroic, ultra-microscopic crystalline needles similarly orientated (luteocobaltic periodosulphate; E. H. Land, 1934) is, at least in a spectral interval comprising the great majority of visible rays, formed mainly of polarized light. In recent years, polarizing foils, which have the advantage of not scattering any light, are prepared from stretched cellulolic materials.

Polarized light remains polarized after reflection from a polished surface, but it is de-polarized by diffusion on a mat surface or by passing through a ground glass.

If two polarizers are placed one behind the other, the light polarized by the first passes freely through the second if the planes of polarization are parallel. It is totally extinguished if these planes are mutually perpendicular, and partially extinguished in all the intermediate positions, and to an increasing extent as the angle between the two planes approximates to a right angle.

At first, the prohibitive cost and very narrow angle of field of effective polarizers restricted the use of polarized light in photographic practice. With the introduction of the polarizing screens, such as the Polaroid, the Eastman Pola Screens, Zeiss Herotar Screens and Merté's Polarization Plates, which can be obtained in fairly large sizes, and with reasonable efficiency in the visible spectrum, numerous applications have been made possible.

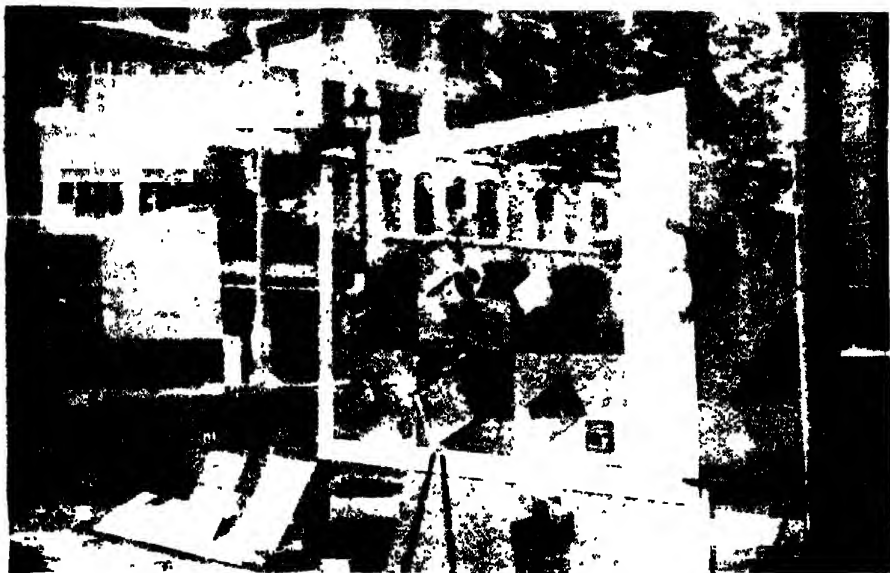
The fact that these polarizers extinguish all components of vibration other than those orientated in the plane of polarization would, in the case of colourless polarizers, cause the exposure to be doubled. However, most polarizing screens used in photography have a certain density and may have a colour from grey to brown and so these factors contribute to the need for a still greater exposure time.

For some purposes it is only necessary to use one polarizer, mounted on the lens. Others require at least two polarizers, one on the lens and one in front of each of the sources of light illuminating the subject.

By using one polarizer it is possible to decrease the luminosity of a blue sky without modifying the brilliance of other parts of the subject, and to decrease very considerably reflections on all brilliant non-metallic surfaces (glassware, water, earthenware, lacquered metal and other varnished objects). This is done by directing the axis of the lens at an angle of about 35° to the surface to be photographed. Thus, objects behind a transparent surface will be clearly seen (Figs. 11.2A and 11.2B), or the actual texture of the subject will become apparent. The correct orientation of the polarizer must be found by examining the image on the ground glass screen of the camera while rotating the polarizer in its own plane.

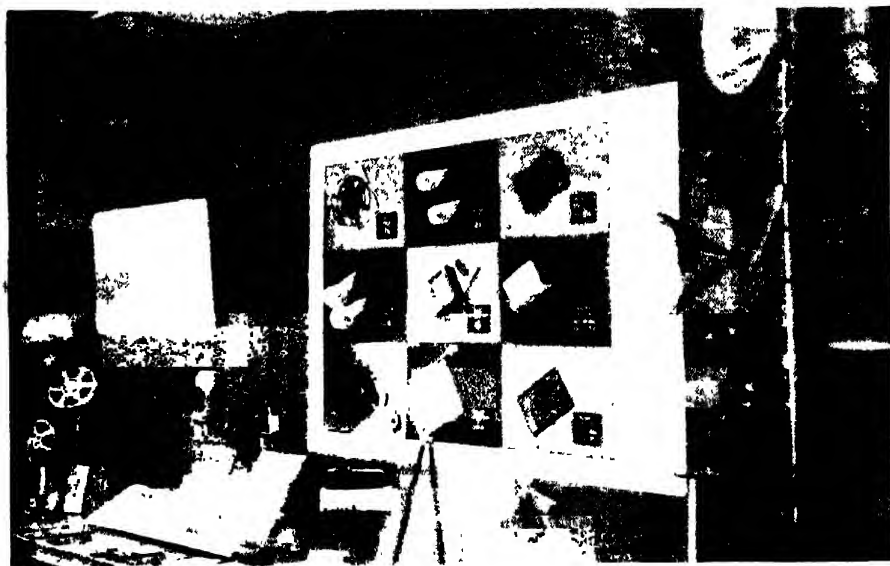
If a number of objects are illuminated by polarized light and photographed through another polarizer, reflections from all brilliant surfaces (including metals) can be decreased, whatever the values of the angles between the surfaces of the objects and the camera. These reflections can even be totally extinguished if the planes of polarization are crossed; this orientation is especially adopted for the photography of varnished paintings or of all documents under glass.

This same orientation permits the contrasts to be increased to a higher degree in the photography of documents on mat or granular paper than that of a glazed print as the structure of the



Kodak Ltd.

FIG. 11.2A. PHOTOGRAPH TAKEN WITHOUT POLARIZER



Kodak Ltd.

FIG. 11.2B. SAME SUBJECT PHOTOGRAPHED THROUGH AN EASIMAN POLA SCREEN

paper is eliminated owing to the extinction of all light reflected by the rough surface. On the other hand it is possible to exaggerate these reflections if the polarization planes are parallel, the depolarized light diffused by the non-reflecting surfaces being then reduced in the proportion 2 : 1 relatively to the polarized light of the reflections.

123. Prisms and Mirrors. We will consider here only the inaccurately named total-reflection prisms and the mirrors (at an angle of 45°) as used in commercial photography. They are employed either for obtaining a picture the right way round direct (with certain methods of printing, reversed pictures would otherwise be obtained), or for the photography of ceilings, articles arranged on a horizontal table (jewels, natural history specimens), and, more particularly, for immersed objects.

The ideal reflector is a metal mirror, but unfortunately such articles are very costly; in their place, optically worked glass mirrors, which are silvered on the surface, may be employed, it being possible to protect the silver, to a certain extent, by a very thin coat of celluloid varnish. Ordinary mirrors which are silvered on the back give rise to double images, except those of very distant objects. The silvering on an unvarnished mirror will not adhere to the glass when damp. For periodical cleaning and re-polishing care should be taken to dry the mirror, the cloth, and the polishing rouge (optical quality) by warming. A more robust mirror is obtained by aluminizing or rhodiumizing the glass surface instead of the silvering.

A mirror has the following advantages over a prism: it absorbs less light; does not cause the slightest aberration, and does not limit the angle of view. On the other hand, a mirror possesses the disadvantage of greater fragility in so far as the reflecting surface is more easily damaged.

The one advantage of a prism is the perfect stability of the silvering, which is applied externally on the hypotenuse (and which excludes all possibility of total reflection) without risk of any doubled image. Prisms, however, do not permit of an angle of field greater than about 30° being used without other reflections creeping in. The definition is often slightly inferior at the margins of the field from aberrations, which are the same as for a cube of glass with the side equal to the length of one side of the prism.

Both prisms and mirrors are best mounted

in front of the camera lens, the mounting being on a small board which is interchangeable with the lens board. The reflecting surface should be turned to make an angle of 45° with the optical axis of the lens, in such a plane that, after reflection, the optic axis is either horizontal or vertical, according to the work in hand. This adjustment is only possible after repeated trials with the reflector mounted between the lens and the object to be photographed. In some coin-operated automatic photographic machines breaking the optic axis at a right angle is avoided by placing the hypotenuse face of the prism parallel to the optic axis (Amici mounting); the angle of field is then still less extensive than in a normal mounting. Ordinary mirrors have occasionally been used, in the absence of a wide-angle lens, for the photography of interiors. In this way the effective optical distance between the object and the camera can be doubled, but in the case of brightly illuminated or reflecting objects the definition usually suffers from doubling of the lines, etc. Surface-silvered mirrors have also been used in the construction of cameras which are designed to accommodate lenses of great focal length, so reducing the bulk of such cameras. In such cases, the part played by the mirrors may be compared with that of the prisms in prismatic binoculars for long-distance observation.

124. Lens Hoods. Any light reflected in the lens (§ 60) or which is scattered in the camera and distributed more or less uniformly over the image necessarily lessens the contrast and tends to veil the shadow detail. Scattering of appreciable quantities of light can usually be traced to two causes.

In the first place, small defects in the polish of the lenses and moisture or dust on their surfaces uniformly diffuse a certain proportion of the light which should go towards the formation of the image. Moreover, if the sun, though not necessarily included in the angle of view, is shining on the front of the lens, any defects on the surface of this lens (or on any accessory such as a supplementary lens or colour filter which is placed in front of the lens) will cause a considerable quantity of light to diffuse into the camera. The same effect is produced, although to a smaller extent, whenever a photograph is taken in the open air, since the lens receives light from all parts of the sky, apart from that in the angle of view.

In the second place, the image produced by a lens (§ 57) is considerably greater than the area

that is sharply in focus and in fact very much larger than the area utilized. Any rays of light outside the useful field strike the interior walls of the camera, and these latter, even if mat black, always scatter an appreciable fraction towards the photographic material. From this point of view, the pleated bellows used on the majority of focusing cameras are certainly better than those of soft stretched leather. The only really efficient means of protection, which is very difficult to apply to folding cameras and cameras which are fitted with lens movements

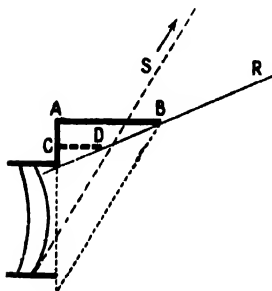


FIG. 11.3. ACTION OF LENS HOOD

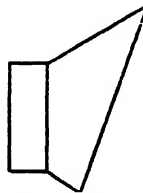


FIG. 11.4. CONE PATTERN OF LENS HOOD

(rising or cross fronts), consists in placing a series of diaphragms of progressively increasing aperture between the lens and the plate, such as those fixed in cameras for aerial photography which are fitted with very long-focus lenses, of which only a small fraction of the field is used.

A lens hood is used to eliminate, or at least to diminish, the various causes of the incidence of stray light on the plate or film, by protecting the surface of the lens from light coming from above and by intercepting as far as possible any light that the lens would transmit to the sides of the camera. The use of this accessory is necessary for all out-door photography, especially for photographs taken against the light, and it is also of considerable advantage when working in a studio with walls having a high reflectivity.

It should be pointed out that of two lens hoods, each shading the lens to an equal extent, the one farther from the lens will be the more efficient from the point of view of protection from the sun. Thus, in Fig. 11.3, the two opaque screens AB and CD both shield the lens from the ray R , but only AB , that is, the one farther from the optic axis, entirely protects the front lens from the direct rays of the sun in

the direction S . It has been stated (C. Puyo, 1906) that for a lens hood to be effective in all cases, i.e. to protect the lens from the sun, whatever its position outside the angle of view, the lens hood should be extended to infinity along the bounding line R , a condition which is obviously impracticable. However, the farther the lens hood is placed from the optic axis, the more efficient it will be, and will remain effective as the sun approaches the limiting line R .

One of the best lens hoods would undoubtedly be a shade such as AB , hinged at A as high as possible, in such a way that the edge B can be raised or lowered to the limit of the field desired (B. T. J. Glover, 1920). Light from the sides is shielded by two small flexible curtains shown by dotted lines in Fig. 11.3. In practice, one is usually confined to fitting on to the lens either a lens hood, represented in section by an obliquely truncated cone (Fig. 11.4), or a cylindrical tube with the end cut obliquely, which is slipped on to the lens. The following methods of making such a tube are suggested: Black felt (taken from an old hat) fastened round the lens with press-fasteners; leather-cloth, kept in place with a strong rubber band; narrow strips of wood glued on to a sleeve of black linen in the manner of the cover of a roll-top desk. As made on any of these lines, a lens hood can be folded flat when not in use. Before making a lens hood of any sort, it is best to make several trials with stout paper, so as to be certain that the lens hood does not cut the angle of view.

If the lens hood is made with a rectangular aperture parallel to the sensitive plate, the dimensions of the opening can be calculated from the formulae

$$l = d + L \frac{D}{E} \quad h = d + H \frac{D}{E}$$

where l and h represent the length and height of the opening, L and H , the corresponding dimensions of the sensitive plate, d the diameter of the effective aperture, E the extension of the camera, and D the distance between the rectangular opening and the optical centre of the lens (or the diaphragm approximately). If the lens is raised by the amount e , the hood must be raised in the same direction by the amount $e \left(1 + \frac{D}{E}\right)$, both being measured from the centre of the image area.

On studio cameras the lens hood is usually formed by a piece of black cloth, supported in front of the camera by a removable metal

frame; or the hood may take the form of a bellows connecting the lens front with an open-front frame, as used for the reproduction of transparencies.

125. Sky Shades. Landscape photography is simplified if the brilliancy of the sky and distance can be somewhat reduced without diminishing the intensity of the image of the ground or foreground. The desired effect can usually be obtained by the use of a yellow filter in conjunction with an orthochromatic or panchromatic emulsion. There are also other methods to lessen the contrast between the sky and the foreground, or to supplement the use of the filter and a colour sensitized emulsion.

The most usual form of commercial sky shade is that suggested by E. Joly in 1892, and consists of a uniformly graded filter of gelatine or glass, usually of a yellow colour. Such sky filters are made in the shape of a long rectangle, which is carried in a mount, allowing it to be raised or lowered according to the effect desired. The filter should be wide enough to cover the lens when placed at a short distance from it. The farther these screens are placed from the lens, the greater is their effect. In the extreme position, i.e. if they could be placed in the plane of the diaphragm, their only effect would be a uniform absorption of a certain proportion of the light without any difference between the sky and the rest of the picture. The effect of a filter such as *AB* depends upon its differential absorbing capacity, which becomes greater as the aperture of the lens is reduced and the distance between the lens and the screen is increased (Fig. 11.5). The same results would obviously be obtained by placing a screen inside the camera (in the position shown by *A'B'*), but it is then difficult to adjust to its best position. In practice equivalent results can be obtained by the use of a sky filter, one half of which is uniformly coloured and the rest plain, the only condition being that it must be used slightly nearer the lens, such as the position *CD*. Such an arrangement even allows the exposure to be shortened especially when using an emulsion which is only sensitive.

Opaque or neutral grey sky shades and polarizers (§ 122) are the only ones suitable for

decreasing the brilliancy of the sky in colour photography.

It should be pointed out that in many cases the moderate use of these accessories distinctly improves the rendering of skies; any exaggeration of the effect should be avoided, since the

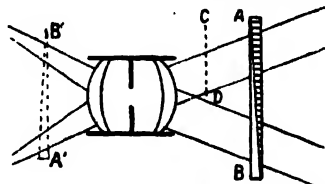


FIG. 11.5. ACTION OF GRADED LIGHT-FILTER

sky takes on an unnatural aspect, suggesting that its colour near the zenith is a deep indigo. Such photographs of clouds can have no value whatever as meteorological records.

126. Soft-focus Attachments. In passing, mention may be made of devices, which, when used with a perfectly corrected lens, introduce slight softening of the definition without altering the focal length or the position of the image.

In particular, the use of a piece of glass with plane and parallel faces, one of which is slightly grooved in concentric circles has been suggested (Lenhard, 1890; C. W. Frederick, 1921). These grooves superimpose a blurred image on to the sharp image transmitted through their interstices. Attachments of this type are readily available under such names as *Duto*, and *Modulo*. If the grooves occur only on the extreme margins of the glass, the closing of the diaphragm will sharpen the definition, since only the central plane-parallel portion of the glass is used.

The use has also been suggested of a kind of comb with long triangular teeth cut from colourless embossed celluloid (Misonne, 1932) arranged to slide so as to cover at will a more or less extensive portion of each bundle of rays, or of a plate with plane and parallel faces which is constructed by assembling two lenses, a plano-convex and a plano-concave, of glasses of about the same refractivity but widely different dispersive powers, thus introducing chromatic aberrations into the picture.

CHAPTER XII

SHUTTERS

127. In the earliest days of photography the word "shutter" was used to signify the cap of a lens, and more recently, various arrangements (flaps, etc.) worked directly by hand. Now, however, it describes any mechanism which allows light to pass through an aperture for a certain definite time, which is usually known as the shutter speed. Except for some special applications, the latter type of shutter was unnecessary until very sensitive photographic emulsions and large-aperture camera lenses became available, as the exposures needed to give good images were of the order of several seconds.

The modern types of shutters can be divided into two groups. In the everset shutters the power needed for operation is obtained during the operation from air compressed by squeezing a rubber bulb, or by the pressure of a finger on the trigger. In order to obtain higher shutter speeds the shutter must be controlled by more powerful closing springs, which have to be set before each exposure; these shutters constitute the second type, often described as preset.

128. **Different Positions for the Shutter.** If we consider the beam of light (see Fig. 12.1), which forms an image in the plane PP after passing through a lens, we can see that the cross-section of the beam *as a whole* is smallest in the plane DD (which is the position of the diaphragm), but that each pencil of rays has its minimum section in the image plane.

As the velocity of the moving parts of a shutter is limited by their having to start from rest, and stop as soon as the limit of their travel is reached (excepting some special types of shutter for aerial photography), it is obviously important to place the shutter where the beam has its *smallest* cross-section. For very short exposures this is best done by uncovering the different pencils of rays where they have the least section by placing as near as possible to the image plane an opaque blind pierced by a narrow slit, which can sweep over the whole surface of the image, as indicated by (1) in Fig. 12.1.

In considering such a *focal-plane shutter* we must distinguish between the effective exposure

time, which is the time for which each pencil of rays is allowed to fall on the film, and the *total time of travel*, which is the time taken for the slit to travel across the whole image. The relative positions of the camera and subject may change during the total time of travel, and if this happens, different parts of the image will not correspond to the same phase of the movement.

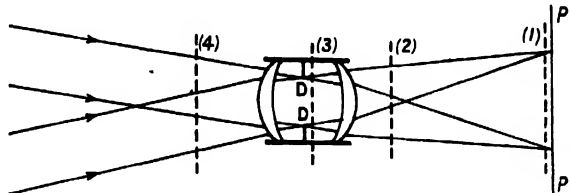


FIG. 12.1 POSITIONS (1, 2, 3, AND 4) FOR OPERATION OF SHUTTER

The distortions then introduced are usually negligible except in the case of extremely rapid motions of the subject or the camera. It is possible that the image will be sharp although distorted, owing to the great difference between the effective exposure time and the total time of travel. In this case though, none of the other usual types of shutter will give a sharp image, as their effective exposure time cannot be sufficiently short. A recent (1949) exception to this general statement is the Symetro-Rapid 800 shutter which, although placed close to the diaphragm, has a maximum speed of $1/800$ sec.

For larger exposures it is better to allow all the pencils of rays to reach the image plane simultaneously and to do this the shutter is placed as close to the diaphragm as possible, as shown by (3) in Fig. 12.1. This allows the shutter to be most compact. As all the film is exposed at the same time, a sharp image will not be distorted, and the exposure received by each part of the film will be roughly proportional to the intensity of illumination at that point in the absence of the shutter.

For reasons of convenience (such as the easy adaption of shutters to any lens or camera without the necessity for special fitting, and great flexibility in the choice of shutters, lenses, and cameras) the shutter is sometimes placed in positions other than those mentioned; it can

be behind or in front of the lens as shown by (2) and (4) in Fig. 12.1. In these positions the shutter has the disadvantage of both the focal-plane and diaphragm types. The various parts of the film are not exposed simultaneously, and the possibility of distortion is introduced (this effect is not so pronounced as with the focal-plane shutter). There is also considerable risk of uneven exposure (this is sometimes done purposely in landscape photography to decrease the exposure of the sky).

Since the size of the shutter opening must be considerably greater than the diaphragm, especially when the angle of view is large and the shutter is same distance from the lens, the exposure time for a given velocity of the moving parts will be greater. In particular the times of opening and closing, during which the shutter

129. Efficiency of a Shutter. Except in the case of a shutter working in the plane of the image, a shutter always takes a certain time to reach its maximum aperture, after which it remains fully open until it begins to close again. The closing also occupies an appreciable time. This is shown in Fig. 12.2 which is traced from a cinematograph film and depicts the complete action of a diaphragm shutter (P. G. Nutting, 1916). The exposure time of the images is $1/30,000$ sec, and the interval between two successive images is $1/1,000$ sec. When the shutter is set for an exposure of $1/100$ sec it takes about $4/1,000$ sec to open; it remains fully open for another $4/1,000$ sec, and takes a further $3/1,000$ sec to close, making a total time of opening of about $11/1,000$ sec.

If a moving object is brightly illuminated, it

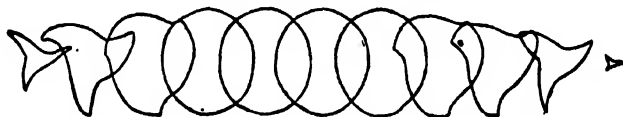


FIG. 12.2. OPENING AND CLOSING OF DIAPHRAGM SHUTTER

is only partially open, become of considerable importance, affecting the efficiency of the shutter and the sharpness of the image (§ 129). A shutter of this type should not open from the centre, since, while it is partially open, it cuts off the more oblique rays although allowing the majority of those only slightly inclined to the axis to pass through, thus exaggerating the differences of illumination between the centre and edges of the image (§ 56). If, however, the shutter opens from one side and closes at the other (e.g. by the movement of an opaque screen with a rectangular aperture) the image at the beginning and end of the exposure will be formed only by rays passing near the edge of the diaphragm. Since the rays passing near the edges of a lens are those having the greatest aberrations, the sharpness of the image will be reduced if the time of partial opening of the shutter is an appreciable fraction of the total time of opening.

Fortunately, the various problems are only of importance when the shutter is at a considerable distance from the lens or the exposure time required is short. Some of these shutters, which work quite close to the lens, give satisfactory results when the exposure time is not less than $1/25$ sec.; they are thus quite suitable for portrait or landscape photography.

can act on the photographic emulsion during almost all the total time of opening—say during $1/100$ sec. But the exposure received by the film will not be equivalent to $1/100$ sec exposure, owing to the appreciable time during which the shutter is partially open. In this case the effective exposure time is only about $7/1,000$ sec. Thus in photographing a moving object, the disadvantage of an exposure of $1/100$ sec as regards blurring of the image is not fully compensated by the ability of an exposure of this duration to record shadow details.

By a simple method we can determine sufficiently accurately the amount of light transmitted by a shutter during its operation relative to that which would be transmitted during the same time if it were fully open. We trace on a piece of card of uniform thickness the aperture of the shutter (on a suitable scale) at equal intervals during its operation. The shapes which are obtained (see Fig. 12.2) are then cut out and weighed together. The weight of each shape is proportional to its area and thus to the light transmitted. Thus the total weight represents the total amount of light transmitted by the shutter (approximately). If we weigh a single piece representing full aperture and multiply its weight by the total number of pieces, we have a measure of the amount of

light which would have been passed if the shutter had been fully open for its total time of opening. Thus, suppose it were found that the eleven pieces together weighed 4.66 g and the single one 0.71 g, the fraction $4.66/(0.71 \times 11) = 0.6$ is a measure of the amount of light passing through the shutter, taking as unity the amount transmitted by the fully open shutter in the same time.

This quantity is known as the *efficiency* of a shutter, and is the ratio of the amount of light transmitted at the shutter speed under consideration to that which would have been transmitted if the shutter had been fully open for the same time. Another way of expressing it is to say that it is the ratio between the effective exposure time and the total time of opening. It is often expressed as 60 per cent rather than as 0.6. As the exposure time is generally limited by the necessity of recording moving objects included in the field, and is often only just sufficient to obtain a photograph in correct tone values, a shutter should be considered more nearly perfect the nearer its efficiency approaches unity, other conditions (e.g. shutter speed) being the same.

It should be noted that the efficiency of a shutter varies with both the exposure time and the dimensions of the effective aperture. With some shutters, operating at their shortest exposures, the blades begin to close as soon as they are fully open, and the full aperture is only used momentarily. On the other hand, at relatively long exposure times the times taken by the shutter blades in opening and closing are substantially the same as in very short exposures, the difference in time being almost entirely due to the increased period at full aperture. When the diameter of the diaphragm is reduced, the *new* full aperture is completely uncovered before the shutter blades have finished opening, and similarly the shutter blades have to close a certain amount before they begin to reduce the aperture. Thus, even if the shutter begins to close again as soon as it is fully open, the complete aperture has been used for a certain definite time. Thus it can be seen that except in the case of a shutter working in the image plane (for which the efficiency is unity), the efficiency of a shutter increases with the exposure time and with reduction of the working aperture of the lens. It can be seen that a shutter is best characterized by its minimum efficiency, since the efficiency is of most importance when the exposures are short and are therefore being made at large apertures.

130. Desirable Characteristics of a Shutter. These are rather numerous, and are rarely found combined in a single shutter.

A shutter should act the moment it is released, with no appreciable lag; it should work with as little vibration as possible to avoid camera shake, and it should not bounce on closing (which might give a second image of the bright parts of the subject). For portraiture silent operation is advantageous. It should not limit the field even when the lens is considerably off-centre, nor limit its effective aperture. It should work equally well in different positions; it should be light, compact, and strong, and it is desirable that regulation of the exposure time can be effected after the shutter has been set without risk of upsetting the mechanism. Its efficiency should be as great as possible. It must not open during setting if it is to be used on a camera in which the sensitive surface is normally otherwise uncovered. Lastly, it should give a reasonable range of exposures which are correctly calibrated and consistent.

Most serious errors are caused by failure to fulfil the last condition. A shutter cannot be expected to give consistent exposures over a period of years, for even although not in use it is impossible to prevent the steel of the springs changing slightly. For this reason springs should not be left stretched longer than necessary, and the shutter should not be kept set in the intervals between use. But over shorter periods (months) the exposure time should be the same at the same setting, especially when the shutter is used several times in succession. Inconsistency is particularly common in shutters in which the regulation of exposure is done by a friction brake, the effect of which is very variable with the temperature and humidity of the air. Grease should never be applied to the brakes (or to any other part of a shutter). Regulation by means of air brake gives sufficient consistency, however, provided the compression cylinder is not worn or clogged with dust.

The calibration of the different settings of a shutter is often far from the truth. In general (for shorter exposures) the true time of exposure is greater than the indicated value. This, however, may be purposely arranged to allow for the fact that amateurs tend to under-expose rather than the reverse. In other cases there is no simple relationship between the times given and the real ones, and with some cheap shutters the indicated times of 1/50 and 1/100 are all actually the same as the 1/25, while sometimes the

exposures indicated as the shortest are actually the longest. Another fault sometimes found in shutters which are calibrated reasonably accurately (some tolerance is obviously necessary when the shutters are first calibrated), is inaccuracy in the neighbourhood of $1/25$ sec, where

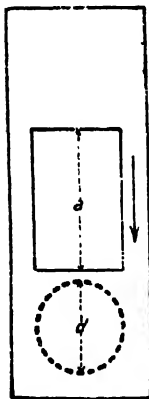


FIG 12.3. THE SIMPLE DROP SHUTTER

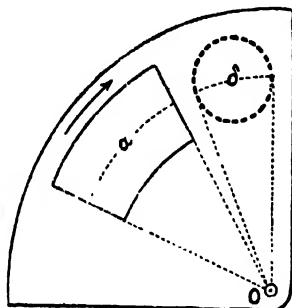


FIG. 12.4. ROTARY SHUTTER

variations of exposure may be relatively large for small variations in adjustment.

The calibration of shutters is susceptible to temperature changes owing to unequal expansion of the various metals used in construction, and variations in elasticity of the springs.

A given range of exposure times is best covered, in the smallest number of different exposures, by a series in geometrical progression, each exposure being preferably double the preceding one.

Exposures longer than one second are not usually made automatically largely because, for focusing, the shutter has to be kept open for an indeterminate time. Usually the coupling of the mechanism is changed by an external control and the operation of the shutter becomes discontinuous, the shutter being opened by the first pressure on the release and closed by the next. This mode of operation is known as a *time exposure*. Another method opens the shutter as the release is pressed and closes it as soon as the pressure is removed; this is a *bulb exposure*. On many shutters the positions of the index corresponding to the two methods of working are indicated by the letters *B* and *T*, the first letters of the appropriate words, and on German shutters by *O* (*offen*, open) and *Z*

(*Zeit*, time). On other simple shutters not allowing bulb exposures, the letters *T* and *I* are used, standing for time and instantaneous, the latter denoting an exposure shorter than $1/16$ sec. On German shutters the letters *Z* and *M* are used, the latter standing for Moment.

131. Summarized Description of Some Types of Shutter. There are far too many existing types of shutters for convenient description, but the chief features of some characteristic types chosen from those commonly used and their predecessors will be indicated. As far as possible the descriptions are in historical order, so that the reader may be able to follow readily the evolution of shutters and compare it with that of photographic technique.

132. Simple Drop Shutters, or Guillotine. The simple guillotine, or drop shutter, consists of an opaque screen, with a cut-out portion at least equal in size to the aperture to be uncovered running in guides and either falling under its own weight or pulled by springs (see Fig. 12.3). Such an arrangement was used in 1845 by Fizeau and Foucault for photographing the sun, but it was not generally employed until the introduction of the wet collodion process in 1855. It then appeared as a clumsy arrangement fitted to the lens hood, the speed of falling being controlled by the slope of its frame. Later it was used as a metal plate passing between the elements of the lens and helped by an elastic band (Jamin, 1862).

Before this, however, in 1858, the rectangular guillotine shutters had been replaced by a circular one (Fig. 12.4), which was much less

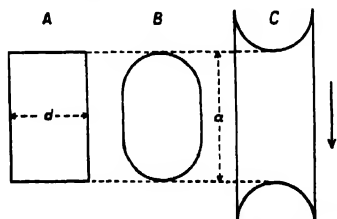


FIG. 12.5. EFFICIENCY OF DROP SHUTTERS

clumsy. The old movement in a straight line was replaced by rotational movement about an axis close to the aperture, which was either in front of the lens hood or close to the diaphragm. The screen can be an opaque sector making a complete revolution each time.

The opening was originally a circle of the same diameter as the aperture to be uncovered, but

in 1880 Joubin showed it to be better to have an opening of which the opening and closing edges were straight. The efficiency of this type of shutter for openings of different shapes was studied by J. Demarcay (1891), and his results are given below.

Consider guillotine shutters with a rectilinear movement and with openings of one of the forms *A*, *B*, or *C* (Fig. 12.5), the height of the opening being *a* and the width *d* (the diameter of the aperture). The efficiency is given in the following table, assuming the shutter to be in the plane of the diaphragm and its movements uniform.

Relation between <i>a</i> and <i>d</i>	Form of opening		
	A	B	C
$a = d$	0.50	0.42	0.57
$a = 2d$	0.66	0.62	0.71
$a = 3d$	0.75	0.71	0.78
$a = 4d$	0.80	0.77	0.83
	$\frac{n}{n+1}$	$\frac{n-0.15}{n+1}$	$\frac{n+0.14}{n+1}$

The opening with convex ends (*c*) has the greatest efficiency, but gives predominance to rays from the edges of the lens; the rectangular opening is preferable. Considering the latter case, the effect of the length of the opening on the efficiency can be easily determined. In Fig. 12.6, distances along the line *AD* are pro-

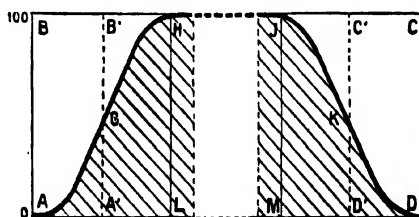


FIG. 12.6. EFFICIENCY, AND LENGTH OF SHUTTER APERTURE

portional to the time from the instant the shutter begins to open, and distances along *AB* are proportional to the area of the aperture uncovered. Curve *AGH* corresponds with the opening period and *JKD* with the closing period, whilst the line *HJ* represents the time during which the shutter is fully open. The efficiency is the ratio of the total shaded areas to that of the rectangle *ABCD*.

In the case of uniform movement the curves

AGH and *JKD* are symmetrical about their midpoints *G* and *K*. Therefore the area of each of the curved triangles *AHL* and *MJD* is equal to that of the rectangles *A'B'HL* and *MJC'D'*. The efficiency is then the ratio of the areas *A'B'C'D'* and *ABCD*. It can thus be seen that the efficiency increases as the distance *LM* (representing the duration of full aperture) increases, i.e. the length of the opening increases.

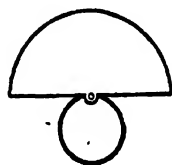


FIG. 12.7.
LANCASTER
ROTARY
SHUTTER



FIG. 12.8.
BERTSCH
ROTARY
SHUTTER

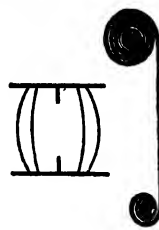


FIG. 12.9.
ROLLER-BLIND
SHUTTER

However, in almost all shutters of this type the velocity is not uniform, and the efficiency decreases as the difference between the extreme velocities increases. If the motion is one of uniform acceleration (e.g. a shutter falling freely) efficiency of a drop shutter with a rectangular aperture falls from 50 per cent to 38 per cent for $a = d$, and from the 66 per cent to 49 per cent for $a = 2d$.

The increase in efficiency caused by increasing the length of the opening is unfortunately accompanied by a still more rapid increase in the exposure time, because the actual velocity of the moving part cannot be increased far beyond 74 ft per sec.

These numerical values are also true in the case of a rotary type of guillotine shutter in which the sector opening has its apex at the centre of rotation. If the sector opening has its apex nearer the aperture the efficiency is increased.

The rotating guillotine shutters of Lancaster (Fig. 12.7) and Bertsch (Fig. 12.8), with efficiencies of 50 per cent and 70 per cent respectively were widely used at one time, but their exposure times were much longer than those usually required in modern practice.

133. Roller-blind Shutters. A development of the guillotine shutter is the roller-blind shutter, which is used in a number of portable cameras. The rigid screen is replaced by a

flexible blind wound on rollers at each side of the aperture (Fig. 12.9). This shutter, first suggested by Relandin in 1855 and developed to its present form by Kershaw, is always used either in front of or behind the lens, the latter being more convenient and permitting different lenses to be used in the same shutter.

The opaque blind, which is made of rubberized

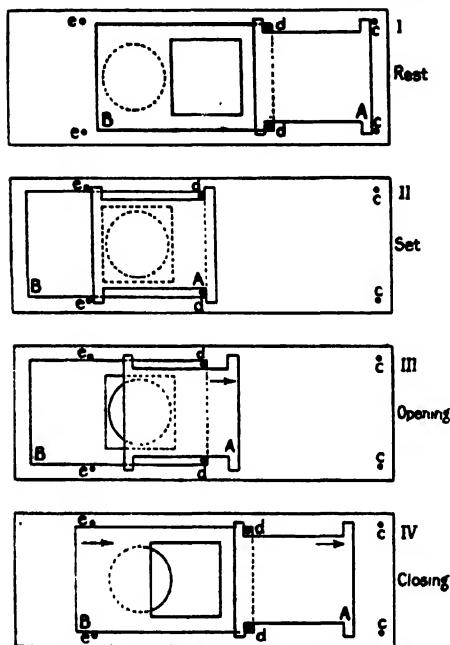


FIG. 12.10. ACTION OF GUILLOTINE SHUTTER

cloth, usually consists of two bands of material in line with one another joined at their edges by narrow strips so as to form one long band with a rectangular opening near the middle. This opening usually has a height of one and a half times its width. The blind is wound by its lower edge on to a roller containing the driving spring. To set the shutter the blind is wound on to the upper roller, either by pulling a cord which is wound around a pulley forming part of the roller or by means of a small key attached to the roller.

The tension of the driving spring may be changed by means of a milled head, and the speed of travel of the blind thus altered (at full tension on some shutters the speed of the blind may be as much as 15 ft per sec). When

this head is turned the corresponding time of exposure is indicated approximately on a dial (for a shutter of about $2\frac{1}{2}$ in. opening the exposures usually vary from $1/15$ to $1/20$ sec, the dial indicating exposures from $1/10$ to $1/50$ sec). The driving spring should not be left in tension when the camera is not in use, but should be released. To do this a spring catch is released, and the milled head should be braked with the fingers to prevent the spring running down too violently.

A side lever can be placed in two positions, one allowing continuous unwinding of the blind, while in the other position the blind is stopped halfway as long as pressure is maintained on the shutter release.

Although several shutters of this type have been fitted with an auxiliary blind to cover the aperture during setting, most models uncover the aperture while the main blind is being set.

The efficiency, which is independent of the spring tension, is the same as that given for the guillotine shutter (rectangular aperture), allowing for the fact that the motion is not uniform. The height of the opening may be measured by setting the shutter half-way and sticking a strip of paper to the upper edge of the opening. The position of the edge is marked on the paper, and the shutter and paper wound on until the lower edge of the opening appears, which is also marked on the paper. The blind is then slowly released so as not to tear the paper, and the distance between the marks measured.

The diameter is taken to be that of the effective aperture of the lens when the shutter is placed in front of it, and slightly less when the shutter is behind; the efficiency is slightly higher in the latter position.

134. Modern Types of Guillotine Shutters. Shutters developed from the rectilinear type of guillotine shutter are used on many types of hand cameras, but in order to combine reasonable efficiency with compactness, the shutter is made of two thin steel plates one covering the aperture before exposure and the other after. The time between the first plate beginning to uncover the aperture to the second plate closing it corresponds with the time of passage of the opening in the simple type. For long exposures the plates are worked independently; for very short, or instantaneous, exposures the second plate is automatically released by the first one when it reaches the end of its travel; or alternatively the first plate actuates a mechanism which releases the second plate after a pre-determined time. In setting a shutter of this

type the two plates either move so that the aperture is never uncovered, or in conjunction with an auxiliary plate which, having covered the aperture during setting, returns to its original position and takes no further part in the shutter's working.

Fig. 12.10 shows diagrammatically how such a shutter works, the driving springs, ratchets and shutter release being omitted for clarity. In the position of rest (position I) the plate *A* rests against the stops *cc* and engages by means of the pins *dd* the plate *B*, the solid part of which covers the aperture. To set the shutter, plate *A* is drawn to the left. It covers the opening in *B* then drags *B* with it until it is stopped by studs *ee* (as shown in position II). When the shutter is released, *A* is set free, and under the force of the driving spring moves to the right and uncovers the aperture (as shown in position III). When it has completely passed the aperture it engages plate *B* and pulls it over so as to cover the aperture again (position IV). The greater the length of the slots in *A* in which the pins *dd* slide, compared with the diameter of the aperture, the greater is the efficiency of the shutter.

135. Flap Shutters. Different types of flap shutters worked directly by hand had been in use for some time when J. W. T. Cadett, in 1878, made a shutter of this type in which the flap was raised by pressing a pneumatic bulb. This apparatus was very clumsy and was fixed to the lens hood. A much neater model was made

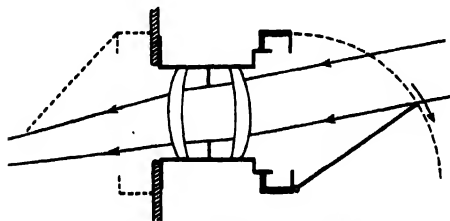


FIG. 12.11. GUERRY SINGLE-FLAP SHUTTER

by C. Guerry in 1880 (Fig. 12.11), and shutters of this type are still being made for portrait photographers. Guerry also had the excellent idea of putting this shutter inside the camera, as shown by the dotted lines in Fig. 12.11. A shutter in this position is equipped with stronger springs, and is operated from a bulb outside by means of a metal connexion through the lens board. Its advantage is that the sitter does not know the exact moment of exposure. The flap, which is very light, is covered with

black velvet and normally rests against the edges of a box which is also lined with black velvet, ensuring that the shutter is light-tight. The shutter is opened by pressure on a rubber bulb, and remains open as long as the pressure is maintained. For long exposures inconvenience is avoided by closing a tap on the tube connecting the bulb to the shutter.

It can be seen from the figure that the lower part of the subject will be exposed for longer than those parts which are above the level of the camera. Thus, in landscape photography, the foreground will have more exposure, which may be an advantage as long as exposures need not be less than $\frac{1}{3}$ sec, which is the least this type of shutter can give.

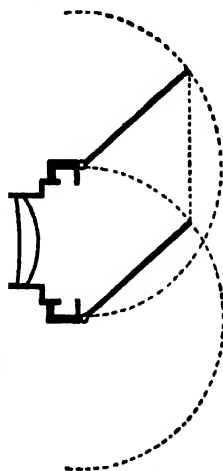


FIG. 12.12. DOUBLE-FLAP SHUTTER

If we represent the exposure at the top edge of the plate by unity, and assume that the flap begins to descend again as soon as it has uncovered the whole aperture, the exposures on the axis and at the lower edge of the plate will be 0.23 and 0.15 respectively. The efficiencies at the top, axis, and bottom are respectively 92, 83, and 50 per cent, and the exposures received will therefore be 92 per cent, 19 per cent (i.e. 83 per cent of 0.23) and 7.5 per cent (50 per cent of 0.15) of what they would have been during the total time of exposure in the absence of a shutter (M. Wastz, 1906). This unevenness is considerably less if the shutter is fully open for some time; if, for example, the total time taken by opening and closing is $\frac{1}{3}$ sec and the time of full opening 1 sec, the relative exposures become 98, 80, and 66 per cent.

Joubert suggested in 1880 the use of a second flap connected to the first and remaining always parallel to it. By means of this double-flap shutter, considerably shorter exposures may be given, but the exposure is now at a maximum in the centre of the plate where it is about 40 per cent greater than at the upper and lower edges. In the form in which it is usually used by portrait

photographers, the second flap can be disconnected so that it becomes a single-flap shutter.

To reduce the time of exposure and also to reduce the variations of exposure across the field, Tanneron (1919) combined the single-flap shutter and the roller blind shutter, the latter



FIG. 12.13. MULTI-FLAP SHUTTER



FIG. 12.14. BELLOWS SHUTTER

being automatically released when the flap is at its top point. In this way, the two disadvantages of the roller blind shutter are overcome. The flap prevents the film being exposed during the setting of the roller blind, and the noise of the roller blind (usually a difficulty in portrait photography) is not heard until it is closing, when it is too late to have any effect on the sitter.

136. Various other Shutters derived from the Flap Shutter. Several types of shutter generally used behind the lens can be traced to the flap shutter.

The multi-flap shutter, shown diagrammatically in Fig. 12.13, consists of a number of light flaps pivoted on horizontal axes and just overlapping in their extreme positions. The main disadvantage of this system is that the light emerging from the lens is never completely transmitted; the flaps, which are always parallel, only pass the horizontal rays completely when they are themselves horizontal but then cut off an appreciable part of the oblique rays. Similarly, if they are partially opened or closed, they transmit completely only some of the oblique rays. Thus this shutter never has an efficiency greater than 33 per cent. Although with a shutter of this type exposures as short as 1/400 sec could be made (Kraus, 1894), it was soon abandoned for general use. It has been used occasionally in aerial cameras, however, and leaves have been arranged radially so as to give a perfectly symmetrical field. A device also used was that of momentarily stopping the blades of the radial pattern when fully open, and an efficiency of 80 per cent was achieved.

Two other types of shutter, of purely historical interest, are the rotating plate, placed between the lens elements and turning on one diameter which, unfortunately, used mainly the outer edges of the lens and the "plug" shutter, resembling the plug of a tap, which used chiefly the central portion of the lens. Both are far too clumsy for modern use.

The bellows shutter is shown, as seen from above, in Fig. 12.14 and is used by many portrait photographers. Two bellows of opaque black cloth are built on light metal frames, rather like Japanese lanterns. In the closed position these bellows form a hemisphere which, when operated by a pneumatic piston, opens about a vertical axis. This has the advantage that the part having maximum exposure is the vertical axis of the image, which is invariably the position occupied by the subject. This shutter does not allow exposures any shorter than those given by a simple flap shutter, but short exposures are rarely needed in the studio.

137. Double-guillotine Shutters. Although in principle a double-guillotine shutter, opening and closing from the centre (Mann, 1862), is for use in the diaphragm, numerous models have been made for use before or behind the objective. One of the best of these, although it was first designed years ago (L. R. Decaux, 1893), is frequently used behind the lens (it may, however, also be used as a diaphragm shutter) without any difficulty if of sufficiently large aperture. This is due to the fact that the time during which the shutter is fully open nearly always represents more than half the total time of operation of the shutter.

In this shutter, which is represented closed and open in Figs. 12.15 and 12.16, (E. Wallon, *La Revue de Photographie*, 1906 and 1907) the two blades V_1 and V_2 , instead of having rectilinear movement, are guided by horizontal grooves a_1b_1 and a_2b_2 , and joined by a long member to the end of the arm B_1B_2 , which rotates about the pivot M and is brought into its position of rest by the spring r . The driving spring R is coiled round the piston rod in the body of the pump P . This pump is full of air, which the piston, under pressure of the spring R , compresses to the end of the cylinder, where it escapes through very small holes, the exact size of which may be regulated at will by rotation of the button p , which has marked on it a series of numbers corresponding to different exposures.

An extension of the piston rod carries a rack which engages in the toothed wheel Q , which is

directly connected with the setting lever, and which is fixed to the cam S which forms the vital part in the mechanism. When the key for setting the shutter is pressed, the rack moves towards the right, thus compressing the driving spring and turning the sector S anti-clockwise.

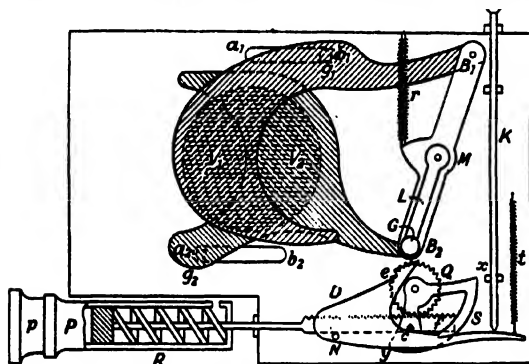


FIG. 12.15. DOUBLE-PLATE SHUTTER—SET

This presses by the tip x on the pin G of the lever L , which is joined at M on the arm B_1B_2 , and which is slightly displaced from its position of rest sufficiently for the sector to pass by, the lever returning quickly to its normal position, and pin G being thenceforth pressed against the sector. The triangular pin C of the cam is then caught in the notch e of the bolt D , which pivots round N and is acted on by the spring t , the shutter thus being set without any movement of the blades V .

If the bolt D is lowered by pressing on the rod K , the pin c is set free and on being released the spring impresses on the cam a rotation in the opposite direction to that previously described. The lever L is pushed towards the right, but in this direction it engages the arm B_1B_2 , and consequently moves the blades of the shutter, the aperture of which is fully opened when the cam has turned through about 90° , the pin G being pressed against the cam. Before this pin is set free, thus allowing the shutter to close, the whole of the sector S shown by the arc xy must pass under it. The time this takes to pass is the time of full aperture, after which the plates close under the influence of the spring r . The air brake does not act appreciably during the actual opening or closing of the shutter, the air not being sufficiently compressed to have any effect on the

driving spring R . In fact, the action of the brake only affects the duration of the exposure at full aperture.

For very long "time" exposures, the holes in p through which the air escapes are almost completely closed. The movement of the cam is then very slow when the pin G approaches the end x of the sector S , and if there is no longer any pressure on the rod K , the pin c is stopped by the notch f before the blades close; a second pressure on K releases c and the shutter closes.

The times of opening and closing are about $1/400$ second; the shortest time at full aperture is also about the same, so that the shortest total exposure is about $1/120$ second, with an efficiency greater than 60 per cent. This rises to about 80 per cent for an exposure of $1/50$ second, and increases continually with the exposure, as is the case with the majority of shutters.

138. Diaphragm Shutters. The first shutter with several pivoted blades opening like the leaves of an iris diaphragm and operated simultaneously by an internal ring concentric with the diaphragm appears to have been made in 1887 by Beauchamp and Dallmeyer.

Some of these shutters, with a large number of blades (e.g. 10 in the *Volute* and the *X-Excella*),

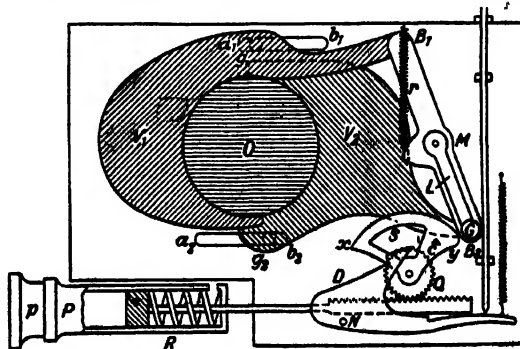


FIG. 12.16. DOUBLE-PLATE SHUTTER—OPEN

are actually iris diaphragms, the leaves opening just sufficiently to form the boundary of the desired aperture as indicated on a scale, during a given time, as shown by a second scale. The efficiency of these shutters is not particularly good, about a maximum of 50 per cent for a uniform movement of the leaves, but this can

be slightly increased by choosing a suitable movement. Also, the construction of these shutters is somewhat complicated, which usually results in a higher price and a more fragile construction than in shutters having an iris which is quite separate from the shutter leaves.

Generally the number of leaves is three or four, but sometimes may be two or five. For a suitable form of leaf the external diameter of the casing of the shutter should, for a given aperture, be smaller as the number of leaves is made greater (Lan Davis, 1911), although manufacturers have not always made the best

increases.¹ The table given below gives for different numbers of leaves (J. Demarçay, 1905) the efficiencies calculated for the case in which, instead of turning round pivots, each one slides in a direction parallel to a radius, the assumption being made, in agreement with general practice for the shortest exposures, that no brake is used.

Number of leaves	2	3	4	6	∞
Efficiency	0.424	0.367	0.351	0.341	0.333

Many older shutters of this type are fitted

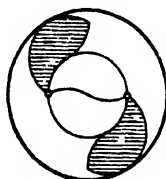


FIG. 12.17.

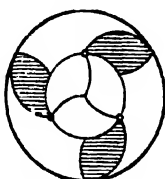


FIG. 12.19.

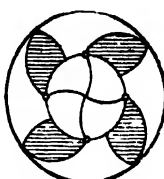


FIG. 12.21.

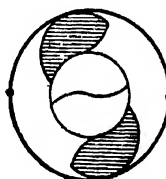


FIG. 12.18.

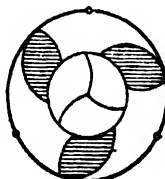


FIG. 12.20.

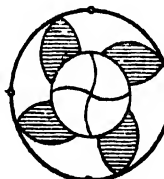


FIG. 12.22.

THEORETICAL FORMS OF TWO-, THREE-, AND FOUR-LEAF DIAPHRAGM SHUTTERS

use of this fact. The table below gives the theoretical diameter of the casing for different numbers of leaves, the diameter of the aperture being taken as unity.

Number of leaves	2 or 3	4	5	6	8	10	20	30
Diameter of casing	2	1.93	1.83	1.73	1.59	1.49	1.26	1.17

Figs. 12.17–12.22 show the theoretical forms of leaves corresponding with shutters fitted with 2, 3, or 4 leaves, according as to whether these pivot around points (marked by small circles) situated on the edge of the aperture or on the edge of the casing.

This advantage of shutters having several leaves is, however, to a great extent counter-balanced by the fact that, for a given method of construction and the same law of movement, the efficiency diminishes as the number of leaves

with air brakes for regulating the exposure, the brake only being used during the period of full aperture so as to increase the efficiency. On more modern shutters this regulation of exposure is carried out by an escapement mechanism.

With all shutters, and especially with those of this type, the minimum exposure increases very rapidly with the diameter of the aperture.²

¹ This law would not hold for leaves in the form of sectors dividing the diaphragm into equal parts and opening by a translatory movement of each of the sectors in a direction along the length of its centre line, or by rotation around a pivot at some distance away. Such arrangements, however, present considerable difficulties in practice.

² Considering shutters of the same type and different diameters d working in the same time, and supposing that the thicknesses are not increased, the energy absorbed, $\frac{1}{2}mv^2$, varies proportionally to d^4 , since m is proportional to d^3 and v to d . Therefore mechanical damage would occur in a very large shutter which opens and shuts in the same time as a small one.

but at the same time the efficiency tends to diminish because the exposure can only be reduced by a change in the time of full aperture.

The results of numerous tests carried out at the National Physical Laboratory (T. Smith, 1911) on this type of shutter have shown in some exceptional cases exposures of $1/340$ second to have an efficiency of 46 per cent. Generally, however, the minimum exposure time is nearer $1/200$ second with an efficiency of about 54 per cent, which rises for longer exposures and becomes practically equal to 100 per cent when the exposure is of the order of 1 second. The relative values of the extreme exposures which are automatically controllable

leaves from the closed to the open position corresponds with a very small rotation of the ring *A*.

The ring *A* may be controlled by two different methods; either by direct action of the trigger release and without previous setting, for "time" and "bulb" exposures and relatively short exposures of about $\frac{1}{2}$ second with very low efficiency, or by using, after setting, a driving spring and an air brake, the only rôle of the release then being to set free the pieces which were locked in setting the shutter.

The movement of the lever to set the shutter engages a spur which is integral with the ring *A* in an arm which, from the moment of release, is connected with the driving spring, the setting being effected without any movement of the leaves, thus removing the risk of the aperture being uncovered. At the moment of release the ring *A* starts to rotate and continues to do so until full aperture is reached. The air brake now comes into play and prolongs the time of full aperture as required until the spur in the ring *A* frees itself from the arm to which it was previously fixed, the leaves then closing under the pull of the spring.

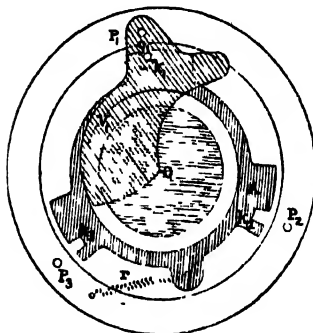


FIG. 12.23. COMPOUND SHUTTER (DECKEL), CLOSED

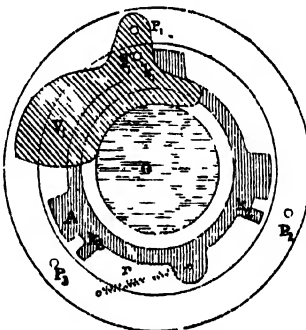


FIG. 12.24. COMPOUND SHUTTER, OPEN

by the shutter often exceeds 200 to 1. On shutters, the time scale of which can be regarded as reasonably accurate, the errors are of the order of 15 per cent, but on some types the error is considerably greater than 50 per cent.

For some years several makers have supplied shutters with a delayed action release (self-timer). An interval, either constant (usually about 10 sec) or adjustable within certain limits, elapses between the pressure on the shutter release and the action of the shutter.

139. As an example of this type of instrument we will consider the *Compound* shutter (F. Deckel, 1905) having three or four leaves according to the diameter of the aperture. This is represented diagrammatically in Figs. 12.23 and 12.24 (E. Wallon), for the case of a three-leaf shutter, one leaf only being shown to avoid complicating the figure. The leaves *V* pivot round the points *P* in a fixed ring and are operated by the pins *g* engaging in the radial notches *h* of the movable ring *A*. It will be seen that the movement of the

The brake consists of a cylinder closed at its two ends and fitted with a piston having a narrow slot communicating with the two ends of the cylinder. Displacement of the piston compresses the air on one side and rarefies it on the other. The resistance to the movement of the piston depends on its original position and has a minimum value when the two compartments at the ends of the cylinder are equal. The variation of exposure is controlled by displacement of the piston *P* (Fig. 12.25) before the shutter is released. This is effected by rotation of the disc *D*, which is graduated in exposure times (1 sec to $1/250$ sec), and which engages the cam *C* moving the bent lever *L*, one end of which is fixed in the piston through a longitudinal slot in the cylinder, and the other, by means of the curved arm *B*, to a drum containing the driving spring.

140. *Escapement-controlled Diaphragm Shutters.* A development of the air-brake system of speed control described above is the use of a

clockwork escapement mechanism, a system which has become common in shutters of the Compur type. The general system of operation is similar to that of the compound shutter previously described, but the rate of rotation of the operating ring is controlled by an escapement mechanism incorporating a gear train for the lower speeds. To obtain the highest speeds, an extra driving spring is brought into operation,

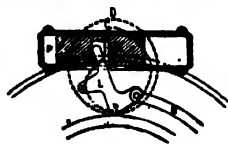


FIG. 12.25. SPEED ADJUSTMENT OF COMPOUND SHUTTER

which speeds up the whole operation, and leaves the efficiency practically unchanged. With shutters of this type, reasonably high speeds can be obtained; on the smaller models, speeds of $1/500$ sec with efficiencies of 60 per cent are obtainable. At $1/100$ sec, the efficiency is about 74 per cent, and at $1/25$ sec, about 92 per cent.

The calibration is usually much more accurate than with everset shutters, but the speeds are nevertheless often considerably slower than indicated, especially at the short exposure end of the scale.

141. Everset Diaphragm Shutters. There are in use a great number of everset diaphragm shutters which usually indicate speeds of $1/25$, $1/50$ and $1/100$, in addition to T and B . In these shutters, the action of pressing the shutter release first sets the driving spring, and the shutter is triggered by further pressure. On these shutters, the various speeds are obtained by variation in the tension of the driving spring, or, on some, an escapement mechanism controls the action in much the same way as on a preset shutter. These shutters are fitted to a large number of cheaper cameras, and the calibration is seldom accurate, it being quite common for speeds of $1/25$, $1/50$ and $1/100$ to be practically the same. The efficiency is rarely more than 75 per cent and is often much less.

142. Focal-plane Shutters. The so-called focal-plane shutter is a drop shutter having a flexible blind consisting of an opaque fabric or of an assembly of metal slats which works in a plane parallel to the film, and, at least in principle, at a very short distance from it. The important feature of this shutter is that it can be used with a very narrow slit, thus giving a very short

effective exposure time with almost maximum efficiency if the slit passes very close to the image (which it unfortunately seldom does). At the same time, the image may be deformed, the deformations becoming greater as the velocity of the moving parts of the image increases relative to the mean velocity of the slit during its passage across the image.

Suppose, for example, that after equal intervals of time, the slit (Fig. 12.26) occupies successively the positions F_1, F_2, F_3, F_4, F_5 (purposely made unequal distances, since the velocity of the slit is rarely uniform). Suppose, also, that at the same moments the image of a straight vertical moving line occupies respectively positions denoted by I_1, I_2, I_3, I_4, I_5 . The little elements of this image which are photographed at each of the moments considered, represented by the points A, B, C, D, E , will therefore not give a vertical straight line in the photograph, but a complex curve depending on movement of the slit, and the image. It becomes a straight line if at all times the velocities are proportional, but would only be vertical if the straight line object remained stationary during the total time of exposure. Obviously, Fig. 12.26 assumes a very extreme and improbable velocity of the image, and exaggerates almost to the point of absurdity

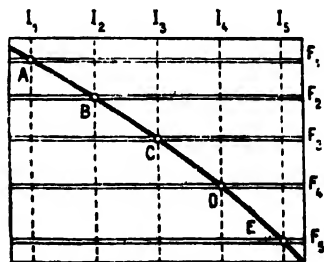


FIG. 12.26. ACTION OF FOCAL-PLANE SHUTTER

the deformations which are produced in practice. These are not generally serious except in cases such as the images of the wheels of rapidly moving vehicles photographed at close quarters, e.g. cars on a racing track; the circular wheel is in such cases reproduced as an ellipse, and in extreme cases the spokes are actually curved inwards. No shutter placed between the lens would allow of exposures as short as those necessary for photographing on a relatively large scale moving bodies having similar velocities. Of two evils, the least must be

chosen, and if one really wants a photograph under such conditions one must be prepared to find it deformed. It should, however, be clearly understood that it is no use trying to make precise measurements on a photograph which has been obtained by using a focal-plane shutter.

The focal-plane shutter, the use of which for ordinary photographic practice appears to have been suggested by H. Farmer in 1882, was not made commercially until after its use by

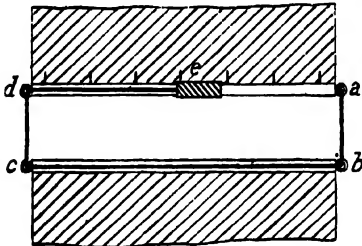


FIG. 12.27. SLIT ADJUSTMENT OF FOCAL-PLANE SHUTTER

O. Anschütz, in 1888, for studying the attitudes of moving animals.

The effective exposure time can be varied in two ways. Variations in the tension of the driving spring affect it, although the extent is only small. In some modern cameras having focal-plane shutters covering a wide range of speeds the velocity of the blind can be varied mechanically. Apart from special cases, however, the majority of adjustment is carried out by varying the width of the slit.

In its original form the focal-plane shutter consisted of a blind made in two pieces, each attached to a sufficiently rigid rod and joined together by a cord in such a way that the width of the slit, that is, the distance between the two rods, could be varied within sufficiently large limits, as shown in Fig. 12.27. In order to do this, the cord, starting from one end *a* of the rod, passes through the rings *bc* to the end of the other rod, then up through the ring *d* at the opposite end of the first rod, being finally attached to the friction-slider *e* which slides along the rod *ad*. The slit edges having been adjusted parallel, the aperture of the slit may be read off from graduations on the slider. Setting of the shutter and adjustment of the spring tension, as also the release of the latter after use, are done in the same way as in the case of the blind shutter mounted on the lens (§ 133). Exposures of the order of a second are given by

hand by simply using the lens cap after having wound the blind beyond the setting position until a slit of width equal to the size of the image to be formed is obtained. Many of these shutters do not give exposures of the order of 1/10 second, for which it is necessary to mount an auxiliary shutter on the lens.

As soon as it was realized that a continuous variation of the width of the slit was unnecessary, the slit regulated as described above, necessitating opening the camera each time it was desired to change the exposure, was replaced by a series of fixed suitably-chosen slits, separated one from the other, in the same blind, by distances which were at least equal to the width of the image (R. Hüttig, 1900). According to the amount of blind which is wound on to the setting roller during setting, so one or other of the slits crosses the image field when the shutter is released, the blind being automatically stopped as soon as one slit has traversed across the whole image. The mechanism is such that the blind cannot move past this stopping point and thus bring into the field one of the slits in the part of the blind which was previously wound on to the setting roller. A pointer outside the camera with an indicator mechanism shows the width of the slit available when the shutter is set. The slits are usually arranged in such an order that, merely by changing them, the tension of the driving spring automatically increases as the slit becomes narrower, thus causing the total time of travel to decrease as the slit width decreases, the effective exposure time being decreased in both ways.

These shutters have the disadvantage of exposing the film during setting, and it is desirable that they work in conjunction with an auxiliary blind or flap which covers the field automatically during setting. Such a blind or flap is moved by the shutter release before the blind begins to move. In the reflex camera the flap is also the mirror, which is made to swing out of the way before the shutter operates. Attempts have also been made to interlock shutter setting with a flap so that the shutter cannot be set if the flap is open and the flap cannot be opened before the shutter is set.

In modern types of focal-plane shutters this disadvantage is avoided by various devices which at the same time allow the width of the slit to be regulated from outside. For example, two separate blinds may be used, of which one, stretched between the driving roller *B* (Fig. 12.28) and the setting roller *A*, has a fixed

slit ab , of height usually equal to the width of the image. The other, which runs between the driving roller D and the setting roller C , ends at d and is wound round C by means of strips continued from its two sides. The setting rollers

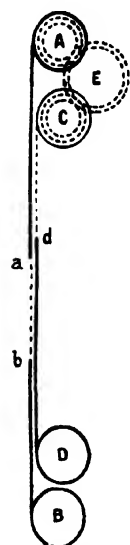


FIG. 12.28.
ADJUSTMENT BY
TWO BLINDS

A and C are operated by a common key integral with the toothed wheel E which engages simultaneously the pinions mounted on the axes of A and C . The pinion A is keyed to its axle, but the pinion C is held on its axle only by friction. When the blind CD is as far down as it will go, the edge d having passed the limits of the field, the setting key can still be turned and the blind AB raised until the width of the desired slit, as indicated externally on the camera, is obtained between the edges a and d of the two blinds. Ratchet arrangements thereafter prevent any relative displacement of the two blinds, after the width of the slit has been adjusted, both during the operation of the shutter, and also at setting, during the passage through the field of the slit ab , which is covered by the blind CD as soon as the photo-

graph has been taken.

The most perfect arrangement of a focal-plane shutter camera was devised in 1899 by G. Sigriste. In this camera, which unfortunately is no longer made, the slit, formed by two heavily-bevelled sharp metal flaps, moved only $1/10$ mm from the plane of the sensitive emulsion. The parallelism between the flaps was so good that the width of the slit could be easily reduced to about $1/10$ mm. The two metal flaps were joined to the front of the camera by a corrugated bellows of such section that even at the extreme ends of its travel it did not intercept any of the useful beams. Springs which acted as brakes during part of the movement and during the other part acted in a way to help the movement, gave a practically uniform velocity to the slit. By variations in the width of the slit and in the tension of the driving spring, 120 different times of exposure could be automatically obtained. These were indicated exactly for two different positions of the camera, held normally or side-

ways, from $1/40$ second up to $1/5,000$ second with an efficiency which did not differ appreciably from 100 per cent. During setting the slit was automatically covered by a metal plate, thus ensuring that the plate was not accidentally fogged.

A camera employing a focal-plane shutter with 100 per cent efficiency is the Aerophote, a camera for aerial photography using roll films, in which the edges of the slit actually slide in contact with the emulsion.

143. In the case of most focal-plane shutters the velocity of the blind varies quite appreciably during its time of travel. The blind, starting from rest, possesses considerable inertia which, in the case of very short exposures and very feeble illuminations, causes the exposure along the edge of the image first uncovered to be considerably greater than at the opposite edge. Even though the tension of the driving springs may be decreasing, the acceleration of the slit is very definite, its velocity at the end being often double that at the start. Fig. 12.30 shows, from the measurements of Verain and G. Labussière (1918), the variations of this velocity in the case of the focal-plane shutter of the 18×24 cm cameras of the French Military Aviation.

In some modern miniature cameras this variation in speed of the blind is compensated adequately (and sometimes even over-compensated) by varying the width of the slit during the travel of the blind. The same effect can be

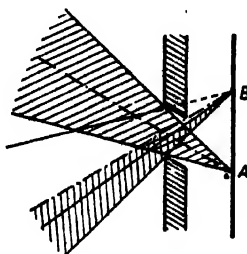


FIG. 12.29. COMPENSATION FOR ACCELERATION
OF THE BLIND

obtained if the effective width of the slit can be changed without changing its real width, and this has been done (Zeiss Ikon, 1935), as shown in Fig. 12.29. When the slit is at one edge of the field the pencil of rays reaching the film (A in diagram), has a larger angle than when at the other edge (B). Thus the effective exposure

changes as the slit crosses the film. It can be seen that the change is greater when the slit is narrowest and the effective exposure shorter; this change is as it should be.

Except in special cases the average velocities of the blind corresponding to the extreme tensions of the driving springs are practically the same. On modern makes of shutters these extreme velocities are in the ratio of 1 : 1.20 or of 1 : 1.54. It is only on very carefully-made shutters that this ratio reaches a value of 1 : 2. (In the Sigrist camera this ratio is as much as 1 : 6, which shows how much room there is for improvement in the construction of

slit MN in the blind R , which is at a distance e from the sensitive film. The planes through the edges of the slit and bounded by the edges of the aperture determine on the one hand a zone MAN inside which the illumination is the same as in the absence of a shutter, and, on the other hand, a zone MBN of which the regions not common with the preceding zone receive light from only a fraction of the lens aperture, which fraction becomes less as the distance from the zone of full illumination increases.

Calculations which cannot be reproduced here show that, when the zone of full light reaches the emulsion layer ($a > e$), the efficiency

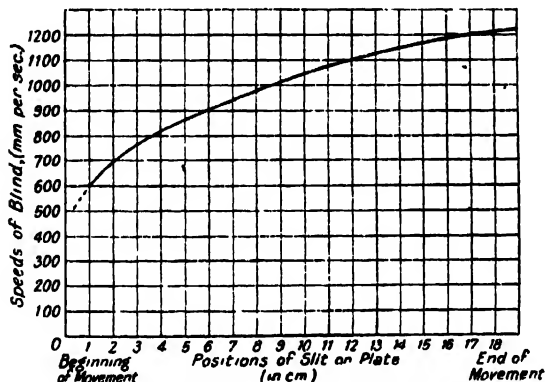


FIG. 12.30. VARIATION OF SPEED OF BLIND DURING EXPOSURE

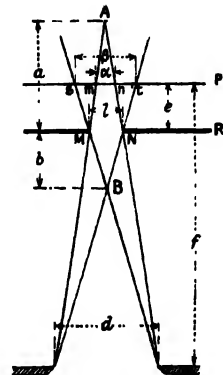


FIG. 12.31. EFFICIENCY OF FOCAL-PLANE SHUTTER

more common types.) In some modern focal-plane shutters covering a wide range of speeds the rate of travel is decreased by means of an escapement mechanism in order to obtain the longer exposures.

Accurate measurements of exposure times have shown that the values of effective exposures indicated on many focal-plane shutters are very much less than those that actually are obtained, the error frequently being as much as 100 per cent.

Except in rare cases where the edges of the slit are in actual contact with the emulsion, no point of the sensitive film passes suddenly from complete darkness to the full illumination which the lens would produce in the absence of the shutter.

Consider a cross-section (Fig. 12.31) through the optic axis perpendicular to the slit. Let d be the diameter of the lens aperture, f its distance from the emulsion P ; l the width of the

is equal to the ratio of the sum of the widths of the band mn , cut at the film by the cone of full illumination, and of one of the bands of the penumbra sm or nl , to the total width of the illuminated band st . This efficiency is given by the expression

$$\text{Efficiency} = \frac{1}{1 + \frac{de}{fl}}$$

The table given below (M. Pau and L. P. Clerc, 1917), calculated for certain cameras of

Focal distance f (inches)	Relative aperture d/f	Distance from the blind to the plate e (inches)	Slit widths (inches)				
			0.04	0.20	0.30	0.76	1.57
10.13	1/5.7	0.51	30.5	71.2	81.4	85.7	94.6
10.13	1/5.7	0.90	19.9	35.4	71.3	83.7	90.8
10.46	1/6	1.57	13.1	37.5	60.0	75.2	85.7

the French Military Aviation, shows the values of the efficiency for different given widths of the slit.

It should be noticed that the time of exposure is not, as one might think, exactly proportional to the width of the slit, but to the width of the illuminated band st , i.e. to the expression $l + (cd/F)$. The exposure is thus proportionally longer for narrow slits than for wide ones. It can be seen from both the expression for efficiency and the table of practical results that the efficiency decreases as the effective exposure time is decreased and also as the lens aperture is increased, and it is unfortunate that these conditions usually go hand-in-hand. On small cameras the efficiency of a focal-plane shutter only becomes of importance at high speeds and large apertures.

It is interesting to note (A. Klughardt, 1926) that in the case of a focal-plane shutter of which the blind moves with a uniform velocity, the effective exposure is constant when only the distance of the blind from the sensitive film is varied. The quantity of light is then the same, whatever the position of the shutter may be, if all other conditions remain the same, but this quantity of light is received in a length of time which increases with increasing distance of the blind from the emulsion.

144. Practical Rules for the Use of Focal-plane Shutters. Over a considerable range of exposures, a given effective exposure time may be obtained under different conditions, since an increase in the width of the slit can be compensated by a greater velocity of the blind brought about by increasing the tension of the driving spring. For any given exposure it is best to adopt the greatest possible speed of the blind; by doing this the total time of travel is reduced; so also is the possible deformation of moving objects, and the wider slit which can be used results in an improvement in the efficiency.

In addition there is the question of the best position for the shutter in order that the deformation may be kept reasonably small when photographing a very rapidly moving object. If the slit moves in the same direction as the image, the latter will appear to be lengthened; if it moves in the opposite direction the image will be compressed. Lastly, the image will appear distorted if these two directions are not parallel, the distortion being a maximum when the movement of the slit is perpendicular to that of the image. This last arrangement should, of course, always be avoided when photograph-

ing rapidly moving objects; it depends on the type of object which of the other two arrangements will give the better result. With fast-moving subjects it is often desirable to swing the camera during exposure so as to keep the image on the film relatively motionless. By this means the distortion may be transferred from the subject to the background. In the photography of subjects such as racing-cars this is not always a bad thing, as it increases the sensation of speed.

Except in the special case just mentioned, the camera should be held quite still during the *total* exposure, which may be much longer than the local exposure. Any movement will cause distortion of the subject even if it does not cause blurring.

In cases where a focal-plane shutter is used for photographing a landscape which contains no quickly moving object, advantage may be taken of the variation of local exposure from one end of the image to the other to reduce slightly the exposure of the sky and the distance.

One can use a flashbulb in conjunction with a focal-plane shutter only if an appropriate synchronizer is used and the useful duration of the flash is greater than the total time of travel (unless a time exposure is used). If this is not so, the subject will not be illuminated during the total exposure, and the negative will be very uneven indeed. It is always necessary to avoid flickering light with a focal-plane shutter, the image produced being formed of light and dark bands. Such sources are neon, mercury, or fluorescent lamps operating from alternating current.

145. Choice of Type of Shutter. Just as no lens can be perfect for all uses, so there is no type of shutter which can really be called universal.

Portrait photography is generally best carried out with inside flap shutters or bellows shutters, as it is essential that they should be silent. Their low efficiency is not generally of much importance, as the normal exposures are of the order of $\frac{1}{2}$ sec.

The roller-blind shutter is perfectly suitable for landscape photography and almost all kinds of industrial photography, mainly because of the ease of employing interchangeable lenses mounted on the shutter. Care has to be taken, however, that the aperture of the shutter is adequate in all cases, and the use of most roller-blind shutters is incompatible with the use of wide-angle lenses.

The photographer specializing in reporting sports, or the study of rapid motion, cannot avoid using a focal-plane shutter, but it must have a blind running very close to the film since high efficiency is indispensable in this kind of work where the exposure is at its absolute minimum. In the choice of a camera with a focal-plane shutter, the question of efficiency is one of great importance.

For general use, the modern diaphragm shutter is probably the best, although the focal-plane shutter associated with the miniature camera has many advantages. In particular, the position of the shutter in the body of the camera, allows lenses to be interchanged in a manner unattainable otherwise. This advantage has resulted in the production of a type of camera which is probably the nearest approach to a "universal," contained in a reasonable bulk, and which is finding a very wide range of application.

146. Shutter Testing. Methods used in shutter testing are very different, according as to whether it is simply desired to determine roughly the exposure corresponding to each setting, or to study the full movement of the shutter leaves or blind.

Some of the methods used for the approximate determination of the exposure can be carried out without any special equipment. Of these may be especially mentioned the process which consists in photographing at a known magnification a luminous or well-lit object moving with a known velocity, and measuring the length of the image registered during the time the shutter is open. As a moving object a steel ball falling freely through a definite distance may be used. Another suitable moving object is a radial line in white on a gramophone turntable which turns at a known rate, or a bright mark fixed to the rim of the wheel of a bicycle, of which, after having exactly determined the gear ratio, the crank is turned at a known rate measured on a seconds watch or a properly-adjusted metronome. In the two latter cases, measurement of the angle subtended at the centre by the arc which is recorded allows the exposure time to be calculated. If this process is carried out with a dark background it is easy, by moving the camera after each exposure to photograph on the same plate, without any risk of confusion, the arcs corresponding to the different shutter settings.

Still another way of shutter testing is to

photograph a source of light which is periodically extinguished with known frequency, by sharply displacing the camera during the exposure, in such a way that the different images of the source are distinct from one another and can be counted. For example, an alternating current electric arc may be photographed, or, if greater accuracy is required, a singing flame adjusted to a diapason (U. Behn, 1901) may be photographed in a suitably-equipped laboratory.

A convenient light source using modern technique is a neon lamp supplied by an alternating current at a suitable known frequency.

An entirely visual process which is very suitable for rapid testing in factories, consists in having a luminous point which is rotated in a circle by a motor, the speed of which may be controlled and measured. The speed is continuously increased until the image seen on a ground glass, and originally limited to an arc of a circle, closes into a complete circle. The time of exposure is then equal to the duration of one revolution (R. A. Woolven, 1913).

A method of determining the effective exposure is to let the light from a constant light source fall through the shutter on to a photoelectric cell. If the electrical output of the photocell (which is proportional to the amount of light) is integrated by a suitable electronic circuit (e.g. the charging of a condenser) and measured, it will be a measure of the quantity of light transmitted by the shutter, and thus, after calibration, of the shutter speed.

For the complete study of the movement of shutters one can, in addition to the cinematographic process already mentioned (§ 129), project the image of the shutter on to a fixed slit behind which a drum covered with sensitive paper is turning rapidly with a known velocity. On development, this gives a record similar to that reproduced in Fig. 12.32, where is also shown the vibration of a diapason (each complete vibration represents $1/3000$ th second), in such a way that the time of opening, of full aperture, and of closing, may be read off directly. In place of a diapason, an intermittent light source (such as a stroboscopic lamp, or a continuous source the light of which is interrupted by a rotating sector wheel) of known frequency may be used. The efficiency is equal to the ratio of the area traced out to that of the rectangle shown by the dotted lines (de la Baume Pluvinel, 1889). By means of this method any peculiar behaviour in the working of the shutter can be investigated, such as the rebounding of the leaves

after closing (Fig. 12.33), excessively slow closing (Fig. 12.34), or variations in behaviour for the same setting. In Fig. 12.35, *a*, *b*, and *c* correspond with three consecutive releases of a given diaphragm shutter without any variation in the adjustment of the exposure time (T. Smith, 1911). This method can also be used for the study of focal-plane shutters.

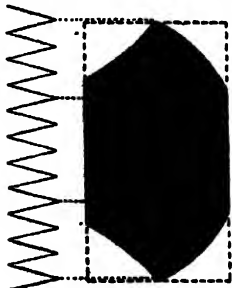


FIG. 12.32.



FIG. 12.33.



FIG. 12.34

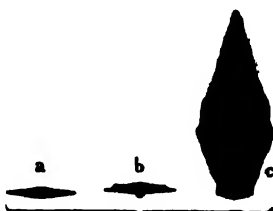


FIG. 12.35.

SHUTTER EFFICIENCY DIAGRAMS SHOWING VARIOUS TYPES OF FAULT

A method suggested in 1905 by M. Hondaille for testing focal-plane shutters is based on the deformation of the images of radii of a rotating disc, photographed as large as possible.

147. Cathode-ray Tube Shutter Testing Instrument. An instrument has been constructed (D. T. R. Dighton and H. M. Ross, 1946-7), for the rapid assessment of shutter characteristics, which plots on the screen of a cathode-ray tube a graph of light transmitted by the shutter

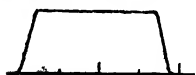


FIG. 12.36. SHUTTER EFFICIENCY DIAGRAM MADE FROM CATHODE-RAY TUBE TRACE

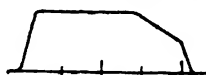


FIG. 12.37. CATHODE-RAY TUBE TRACE SHOWING SHUTTER CLOSING UNEVENLY



FIG. 12.38. CATHODE-RAY TUBE TRACE SHOWING LOW EFFICIENCY



FIG. 12.39. CATHODE-RAY TUBE TRACE

against time (Fig. 12.36). The interpretation of such a graph is discussed in § 132.

The spot, which normally remains motionless at the origin, is deflected vertically proportionally to the output of a photocell which receives light transmitted by the shutter. Horizontal deflection is supplied by a single-stroke time-base circuit, which is triggered automatically by the output from the photocell.

The two deflections thus occur simultaneously when the shutter is operated and the graph is traced. The spot returns to the origin, and then travels along the base line putting in timing marks. The screen has long afterglow properties,

the pattern lasting long enough for measurements to be made. The timing marks can be made 1/10, 1/100 or 1/1,000 sec apart, and the speed of the time-base can be adjusted to cover a total time of opening from 1 sec to 1/5,000 sec.

Peculiarities of operation may be detected readily from the graph: A shutter which closes unevenly is shown in Fig. 12.37; a shutter with

low efficiency in Fig. 12.38 and a shutter with closing "bounce" in Fig. 12.39.

For the study of the motion of the mechanism of shutters, a small discharge flash tube is built into the instrument and may be made to flash at any desired point in the operation, thus enabling the mechanism to be seen momentarily or to be photographed.

148. Shutter Releases. The operation of a shutter may be carried out by the direct

pressure of a finger on the release lever, or alternatively by means of a flexible release, which may be pneumatic, mechanical or electromagnetic. Direct pressure on the release lever is only suitable for short exposures, and always introduces considerable risk of camera shake, which blurs the image.

The pneumatic release consists of a rubber bulb joined by a tube of suitable length to the bellows on the shutter, or on more modern shutters to a small pump operating on the release lever. It is only employed on several types of shutters used by portrait photographers, a long rubber tube being much more delicate than a

metal one, and it is often very desirable that the photographer should not have to wait beside the camera for the whole exposure. The regulation of exposures is sometimes carried out by inserting a connexion carrying a tap, the rate of leakage being controlled by a movable index on a scale calibrated in times of exposure. In order to avoid accidental exposure, it has been suggested that the bulb should have a small hole, which must be covered by the thumb.

The use of metal releases in photography started at the time when the flexible metal controls for bicycle brakes, invented by E. M. Bowden in 1897, were becoming common. These controls consisted of an unstretchable steel wire cable inside an incompressible sheath, made by winding a metal wire spirally around the cable.

In modern cable releases of this type, designed to screw into the small socket provided on most shutters, the method of operation is reversed. The inner wire is pushed and the outer case kept in tension, usually by the cloth cover. A spring returns the cable and sheath to their previous positions as before.

These releases are in general use and are considerably less clumsy than pneumatic bulbs. Unfortunately they are very fragile, since any bend in the sheath gives rise to a permanent deformation and to friction which prevents the cable sliding easily, and they cannot easily be repaired. Also, care should be taken to prevent the release being too curved when rolled up. Special models with reinforced sheath have been made with long lengths of tube for use on professionals' cameras, but this is not at all general.

It should not be thought that the use of a cable release eliminates the risk of shaking the camera completely. It often happens that the relative motion of the cable and sheath can be too great, and after the shutter has begun to operate the camera is shaken by further movement. For this reason it is very desirable that such a release be operated slowly.

The electromagnetic release, which has been used for a considerable time in special apparatus which has to be worked from a distance (in ballistic experiments, or animal photography) has recently been developed for the purpose of flash synchronization. The closing of the circuit operating the flashbulb also operates an electromagnetic shutter release, which can be made to have a suitable delay, opening the shutter when the light from the bulb is approaching its maximum intensity, and thus enabling high

shutter speeds to be used. The flashbulb and release are operated from dry cells.

There are many types of modern shutters which have flash synchronizing contacts built in. Usually the mechanism is simple, firing the flash at the same time as the blades begin to open. It is necessary to use an exposure long enough to allow most of the light from the flashbulb to be used.

A recent development which is usually used on hand-held cameras was introduced because of the difficulty of reaching the shutter release lever when the camera was in use. The release is now operated through levers by a push-button on the body of the camera, thus enabling the camera to be held with both hands.

Some amateur photographers often wish to be included in groups and family scenes which they take, and also in landscapes. Numerous types of release have been made or improvised to achieve this, from systems using a slow-burning fuse, to those employing a long piece of thin black wire or string. Releases have also been constructed depending on the slow flow of a fluid in a pump or upon a clockwork escapement mechanism. Several accessories permit the regulation of the delay between wide limits, and others give a warning of some kind when the release is about to take place. It is worth noting that the delay of the fluid types is greatly affected by temperature, and types using an air escapement mechanism can be very inaccurate at high altitudes; the calibration of clockwork releases is often inaccurate but their operation is usually very satisfactory.

149. Interlocking of the Various Controls. Among the most common mistakes made by photographers are the taking of two photographs on the same section of film, or (less frequently) winding the film on without exposing it.

In order to make cameras more foolproof and reduce the number of mistakes of this type, systems have been devised which interlock the various operations. The most usual one is to have the film transport interlocking with the shutter release; in this case the film cannot be wound on until the shutter has been released, and the shutter cannot be released again until the film has been wound on. In more advanced types, the winding of the film automatically sets the shutter, and as soon as the film has been moved the necessary amount, it becomes impossible to wind it further. Operation of the shutter then releases the film transport and permits the next operation.

CHAPTER XIII

STAND CAMERAS: COMMERCIAL, PROFESSIONAL, AND SEMI-PROFESSIONAL

150. **General Notes.** Hand in hand with the successive improvements in photographic processes, their uses increased infinitely, and thus different types of camera were evolved, each differing to a greater extent from the original form, until, externally at least, they no longer have any character in common, each being designed for a special purpose. This specialization, which is inherent to all progress, leads us to classify the various types of camera according to the purpose for which they are chiefly intended.

It is obvious that with cameras for photographing stationary subjects or posed sitters, the conditions to be fulfilled are very different from those required for instruments for taking instantaneous views or for photographing unobserved a person or animal.

The former, which are intended for commercial or studio work, are generally made in large sizes, without regard to bulk or weight, at any rate within certain limits, since they are intended for use on a rigid stand, and will not be carried from place to place except for special reasons. The latter need to be easily concealed, and will, therefore, always be of small sizes. If they are to be of the utmost service to the user they must be light enough to be carried about constantly, so as not to risk missing any interesting and unexpected subjects.

Modern developments in sensitized materials and the design of equipment have permitted a progressive reduction in the size of the original negative without any loss of quality in the print, even though greater degrees of enlargement are required. The size and weight of the equipment have therefore been reduced but the precision with which it is made has had to be increased to provide the necessary sharpness in the image. Whereas early in the century quarter-plate was considered the smallest possible size, 24×36 mm is now normal and even smaller sizes have been employed.

The stand camera will vary, as regards the different movements embodied in it, according as it is intended entirely for studio use (in copying flat originals, photographing articles for catalogue illustration, or for portraiture), or, as it is chiefly for use out of doors, in commer-

cial photography, architectural or landscape work.

While this is a somewhat arbitrary division, we will confine this chapter to the description of cameras solely for indoor use, and of those which, while portable, are intended exclusively for use on a rigid stand. In the next chapter we will describe cameras generally used in the hand, though suitable for use also on a light stand for exposures of $1/10$ sec or more.

We shall confine ourselves to a brief description, referring the reader to the makers' catalogues for details.

151. **Names and Functions of the Parts of a Camera.** A camera consists essentially of two frames of which one (the front) supports the lens flange, while the other (the back frame) receives alternatively the ground-glass screen, on which focusing is done, or the *dark slide* in which the light-sensitive material is carried from the dark room to the camera and back again. These frames are connected by a *bellows*, similar to the bellows of an accordion, made of cloth or leather, which allows the distance between the two frames to be varied over a considerable range, while shutting out all light except that admitted through the lens.

In the course of these movements the volume of air within the bellows increases and decreases, sometimes to a very considerable extent, and air-holes must be provided in the frame of the ground-glass screen to prevent damage to the bellows. Such vents are often provided by cutting off the corners of the ground glass.

Until recent years, stand cameras were invariably made of wood, usually mahogany, reinforced by brass fittings. Now, however, light alloys are being used increasingly and so-called "all-metal" cameras are available, especially in America.

The lens flange is not fixed directly to the camera front, but to a *lens board* or *lens panel*, which slides in grooves permitting it to move parallel with itself upwards or downwards (*rising front*) or towards the right or left (*cross front*). Several interchangeable panels can each receive the flange of one of a series of lenses in use.

It is well that all lens panels should be inter-

changeable among all the cameras in a studio, or among the cameras used away from the studio in a commercial photographic business.

The two camera frames are held parallel with each other by means of grooves in the *baseboard*. One or other of them is sometimes fixed permanently to this baseboard. The movement of the movable frame (or of the two frames) is generally done by two pinions mounted on one rod. These pinions engage in two racks fixed parallel with the optic axis. Helicoidal racks (with oblique teeth) afford a finer movement. When both frames are movable, the front one is often arranged to be moved directly by hand. In better-class instruments it is often controlled by a winch-screw fixed along the longitudinal axis of the baseboard. In every case it is necessary to be able to fix the frames firmly in the position reached in the course of focusing.

There is a tendency in modern cameras, especially with half-plate field cameras, to replace the baseboard by two parallel rods or even by a single central rod. On this the various parts of the camera can slide easily and be locked firmly in any position. The high degree of hand workmanship required for the fitting of accurate racks and pinions is thus avoided. This new system is particularly adapted for use with all-metal cameras.

Camera extension is the term used to denote the distance between the front surface of the lens panel and the surface of the sensitive plate or film. In order to increase the maximum extension or reduce the minimum extension of a camera in certain circumstances, the lens board is sometimes replaced by an extension piece, consisting of a box, one end of which fits on to the camera front in place of the lens panel, while the other end carries the lens flange. These accessories are usually rectangular in section and are known as *extension boxes*.

In the case of cameras especially designed for portraiture, commercial and landscape photography, it is advisable for the rear frame not to be a fixture in a plane perpendicular to the normal position of the optic axis, but capable of inclination to 10° to 15° on this axis. To do this it is pivoted on horizontal pins fixed to a larger frame which can be moved along the baseboard, and the camera is then said to have a *vertical swing*. A similar mounting on vertical pins is sometimes employed and is termed *horizontal swing* or *side swing*. In order that the swing may be used, if necessary, for restoring perspectives registered on a non-

vertical plane (Chapter XLVIII), the common axis of the pins must be in the plane of the image, for otherwise this operation would entail interminable trials.

When it is necessary to copy transparent objects and avoid reflections from the surface of the object which faces the lens (enlargement and reduction of negatives, etc.), a camera consisting of three frames is generally used. In this, the lens is mounted on the midway frame, while the transparent object is carried by the front frame. If a very long extension should be necessary, the lens can be fixed to this front frame, but as a rule it is preferred to fix it to the middle one, in which case the front frame and the bellows connecting it to the middle frame form a most efficient lens hood (§ 124).

The baseboard of a triple-frame camera is generally formed of two portions sliding one within the other to avoid unnecessary bulk when the maximum extension is not being used. The front frame is then fixed to the sliding extension, and the movement of this extension from the fixed portion of the baseboard is regulated by a winch-screw operated from the rear of the camera. The baseboard of a camera which extends in this way is never as rigid as a one-piece baseboard, and the extension must therefore be supported separately.

In the case of studio cameras and some field cameras, bellows of square section are used. The photographic plates, which are usually oblong in shape, can then be placed one way or the other as desired, the long side being either vertical or horizontal. For this purpose, in studio and copying cameras, square dark slides are often used, fitted with rebates to take the plate in either position. In other cameras, chiefly those of portable square bellows pattern, the rear frame is made square and is fitted with an attached panel (*reversing back*), which carries the oblong dark slide and allows of it being placed either upright or horizontally.

When, as often happens, plates are used of smaller size than the maximum for which the camera is built, adapting holders or *carriers* are placed in the dark slides. It is possible to have a set of these carriers (called *kits* in the United States) fitting in each other and each corresponding with a given plate size.

When, however, a camera is regularly used with small plates, it is generally preferred to employ dark slides of that size, fitting these to the camera back by means of an adapter.

The dark slides used with studio cameras are

nearly always *single slides*, taking only one plate or film. Field cameras, on the other hand, have *double slides* containing two plates, one on each side of the slide.

The slides of studio and copying cameras are usually closed by a flexible curtain shutter, formed of thin strips of wood glued on an opaque fabric (roller-blind or curtain slide). To uncover the plate, this curtain or blind is drawn aside by means of a tag at the back of the slide after the latter has been fitted to the camera. Most dark slides of smaller size are closed by a rigid shutter or by a shutter hinged in one or more places.

If the image seen on the ground-glass or focusing screen is to be recorded with equal sharpness on the sensitive emulsion, it is essential that the plane of the front ground surface of the focusing screen shall coincide exactly with the plane of the sensitive surface as determined by the rebates or turn-buttons.

152. Cameras for Commercial Copying. In making large-size copies of originals, as is done in cartographic and photo-mechanical work, the following arrangement may be employed with advantage, provided the building is not subject to vibration from machinery or heavy traffic. In such a case the various parts of the apparatus may be made to hang from wheels running on a rigid frame suspended by springs from the ceiling. The lens is mounted on a plate fixed to a partition separating the dark room from the studio. Rails, sunk in the floor parallel with the optic axis, carry in the studio a travelling easel and in the dark room a travelling support for the plate, the rails being fitted with carriages and mechanism for moving the latter slowly and holding them fixed. One of the advantages of this arrangement is that a dark slide becomes unnecessary; such a slide would be exceedingly bulky and heavy when the plate is as large as five square feet in area, or larger.

In smaller sizes it is usual to employ a photographic camera of the normal type, but of heavy build in the wooden parts, strongly reinforced with metal, and thus capable of withstanding daily wear and tear. The fine finish and ornamentation often lavished on studio cameras are out of place here. Various movements, such as swing and rising or cross front, which are of great value for other purposes, are useless or a positive drawback in this particular case.

The rigid baseboard, made in one piece, must ensure the strict parallelism of the frames. Its length is usually sufficient to permit not only

of copying to same size, but also of some slight enlargement. For this, the extension must be somewhat longer than twice the focal length of the lens employed. In order that the same lens used for copying same size or on a reduced scale may be used for making copies larger than the original, the baseboard of the camera would have to be of such excessive length as to be unmanageable in ordinary work. When a copying camera is used to make an occasional enlargement, the usual lens is replaced by one of much shorter focal length.

To a greater degree than in the case of any other camera, the maker must assure the absolute coincidence of the focusing plane and the plane of the sensitive plate. This absolute register cannot be obtained if the ordinary kind of carrier be used when employing plates smaller in size than those for which the camera is made. A *universal adapter* must be used. It is formed of two horizontal bars which can be moved up and down between the vertical sides of the dark slide, the arrangement being similar to that used for supporting at various heights the lugs bearing the shelves of a cupboard or bookcase.

Owing to the frequent use of wet-collodion plates in reproduction work, the dark slides are loaded from behind, and the lower bar, of aluminium, is so shaped that the drippings coming from the plate during exposure may be caught on strips of filter paper.

To check register, it is advisable that focusing be done in the dark slide itself after placing a mat glass screen in the rebate provided for the sensitive plate. For this reason the curtain of the slide should be completely removable. This focusing in the dark slide should be done, not on a sheet of ordinary glass, the surface of which is more or less uneven, but on plate glass, on which some transparent patches have been left, e.g. along the diagonals, when matting the surface. The dark slide must run very smoothly in the back of the camera, but without any play, which can be achieved only by making the attaching parts entirely of metal.

Originals to be photographed are sometimes secured by their corners by drawing-pins to a board, which is built up of several layers of wood in order to lessen the risk of warping. Reflection of stray light into the camera is avoided by blackening the face of the board to which originals are fixed. Blackening the front frame of the camera likewise reduces the risk of reflections from glossy prints or such as are mounted under glass. Valuable originals cannot,

however, be pinned; they may be secured between the copying easel and the heads of drawing pins inserted around their edges, or under clips sliding in grooves in the easel, or they may be held flat under glass, using, say, a printing frame fitted with springs (§610); or, if the whole or part of a page of a book that cannot be taken apart has to be copied, a special frame can be used.

Framed documents and mounted paintings are usually held between the jaws of an easel similar to an artist's easel. The copying board may also be held in this manner.

As strict parallelism must be automatically assured between the copying easel, the lens board, and the sensitive surface, the easel and the camera must be mounted on one and the same rigid base, at least one of the two being movable on rails parallel to the optic axis. The orientation of the object holder must be adjustable as required.

In all cases where the floor of the work-room is subject to vibration, the rigid base mentioned above must be arranged so that it is free to move as a whole. This is done either by cords hanging from the ceiling or by springs fastened to another framework resting freely on the floor. The worst that can then occur is that the whole apparatus swings, without, however, any displacement of the camera relative to the original. This enables perfect sharpness to be obtained even if the exposures are of considerable length.

Mention must be made of the cameras, such as the Photostat, used in many public offices (banks and insurance companies) and drawing offices for rapidly multiplying documents. The original is photographed directly on paper supplied in spools. In order to obtain an unreversed copy, the lens is fitted with a reversing prism (§223). The originals to be reproduced are placed flat on a horizontal table, or against a vertical plate, where they are held by suction or by electric attraction. This type of machine is usually handled by non-technical workers, and is almost automatic in operation. In some, even the development and fixing of the paper, cut automatically after each exposure, are carried out in the machine, but this arrangement implies a larger, more costly and more carefully designed layout to avoid injury to the woodwork and mechanical parts by the constant moisture and splashing of liquid.

153. Studio Portrait Cameras. As these cameras are never used outside the studio,

considerations of weight and bulk are altogether secondary to those of stability and rigidity, and of precision in manipulation. The camera is sometimes of the triple-frame type, so as to allow, if necessary, of the copying, enlargement, or reduction of negatives and transparencies. The long extension of a triple-frame camera permits the use of lenses of long focal length when required. When a long extension is not needed the front part of the camera acts as a lens shade, which is an indispensable accessory in a studio, where the great volume of light from walls and roof may cause general fog on the negative as a result of multiple reflections within the lens.

The size of the largest plate accommodated by a studio camera is never less than $8\frac{1}{2} \times 6\frac{1}{2}$ in., and rarely exceeds 12×10 in.

In either of its positions (on the middle frame or on the front frame) the lens must be fitted with a considerable amount of rise and fall, the height generally chosen for it being at the level of the sitter's eyes. The camera back is usually fitted with a vertical swing. This permits a large lens aperture to be used, and yet uniform sharpness is still obtained throughout the image of a seated figure, the knees and face of which are at very different distances. It also allows the plate to be brought into a vertical plane when the front of the camera has been pointed downwards, as in photographing a child, who is often best photographed from some height, that being the position from which a child is usually seen.

The dark slides are generally of single pattern with a curtain shutter, of square shape, and fitted with a series of rebates to take the plates either way; also with sets of carriers. Modern slides are often fitted with devices enabling either glass plates or flat films to be used at will. The focusing screen is marked, usually in pencil, with the outlines of the different sizes in common use.

The *repeating back* with which a studio camera is sometimes fitted enables two or more negatives to be made in succession on the same plate, and allows the focusing screen to be quickly replaced by a slide, the shutter of which has already been drawn. The repeating back is interchangeable with slides of the full size of the camera, and consists of a board with slide bars accommodating a frame that can be pushed along them until checked by stops. This frame takes dark slides of $6\frac{1}{2} \times 4\frac{1}{2}$ in. (in the United States, 7×5 in.) or $8\frac{1}{2} \times 6\frac{1}{2}$ in., and a focusing screen is permanently fixed at one end of it,

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Velvet light-traps half-embedded in this sliding frame prevent light from reaching the plate after it has been uncovered. In the centre of the board there is an aperture of the dimensions of the plate (sometimes with a detachable mask for another size). Notches placed at the proper points of the slide-bars automatically engage with a spring-bolt fixed on the sliding frame.

For easy working the dark slides should be sufficient in number to obviate having to unload and refill them too frequently.

The focusing cloth, which is needed for inspecting the image on the screen, must be of

arrangement giving a larger range of movement. In this there is a table or top, carrying the baseboard of the camera, which top can be tilted on a horizontal axis. The table moves up or down between two or four pillars fixed to a base. Pinions fixed beneath the table engage with racks on the insides of the pillars which sometimes contain counterweights. The top can thus be lowered to within a few inches of the floor, and can be raised to a height limited only by the height of the pillars. Metal bipost stands of this type are widely used.

In either case the stand must be mounted on

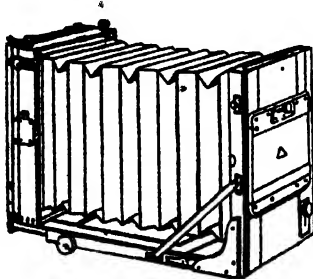


FIG. 13.1 SQUARE-BELLOWS CAMERA

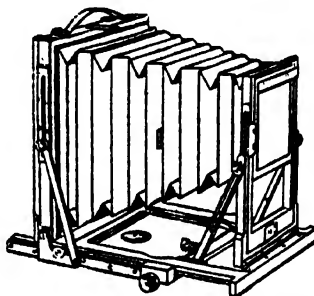


FIG. 13.2 TAPER-BELLOWS CAMERA

perfectly opaque material (very close cross-weave) and of ample size. In a portrait studio the black cloth may be covered with a thin material of light colour. On some cameras the cloth is supported by a light metal frame fixed to the back of the camera and forming a kind of hood which keeps the cloth clear of the operator's head. Not only is this arrangement a more comfortable one, especially in hot weather, but it is required for elementary hygienic reasons where several operators are likely to follow each other at the same camera.

154. The studio camera must be capable of being fixed at various heights and at various angles. The studio stand has long been in the form of a small table, or platform supported on pillars sliding within the framework. Racks and pinions enable the front and the back of the top to be raised or lowered either simultaneously or separately. On this system the maximum height to which the top can be raised is only about 33 per cent more than the minimum height to which it can be lowered. The arrangement is very stable and is still used for certain branches of commercial photography. But for portraiture it tends to be replaced by an

castors, allowing it to be moved easily and rapidly. It is preferable, especially when the stand is to move on carpets, that the castors be replaced by wheels of larger diameter with rubber tyres. Once the stand has been brought into position it can be fixed there by means of four movable rods which project a little under the stand and lift it slightly, usually by operation of a pedal.

Various patterns of stands, of simple construction, similar to the former of the two types described, can be used with studio cameras of small size.

The camera is usually secured to the top of the stand by means of screw clamps.

155. **Portable Stand Cameras.** Cameras for technical, architectural, and landscape photography (commonly known as "technical," "commercial," or "view" cameras) and for outdoor groups may be divided into two principal types: square bellows (Fig. 13.1) and taper bellows (Fig. 13.2). Rigidity is more easily obtainable with the former, though at the expense of some flexibility of movement, particularly of the front frame. The swing front of the taper bellows type must be used

with extreme caution, for any inclination of the camera front tends to cause the lens to work at the edges of the field over which it covers sharply, i.e. under the most unfavourable conditions. As a matter of fact, the front swing should never be used by itself; its purpose is to permit a considerable rise or fall of front by tilting the baseboard of the camera and then readjusting both the front and back into the vertical.

The essential conditions that must be fulfilled by portable cameras are comparatively small bulk and weight, great rigidity even at full extension, and a satisfactory parallelism between front and back. The lens should be capable of being used well above or below the central position. To compensate for insufficient amount of rise or fall, the lens flange may be fixed above or below the central position on the lens panel; and, when using a camera of larger size than the negatives being taken, the carriers for the dark slides may be cut to serve the same purpose. The vertical swing, which is of little advantage when photographing groups, becomes useful in landscape work, and necessary in architectural or technical photography. It must allow of an inclination of at least 15° . The side swing can occasionally be used with advantage, e.g. in reducing the convergence of horizontal lines in architectural photographs taken with a wide-angle lens, or in avoiding the use of a very small stop in taking views of a street with one row of houses much nearer than the other. The maximum and minimum extensions available will be decided by the focal lengths of the lenses which it is intended to use, bearing in mind that in technical photography, the photographing of small objects "same size" (extension of twice the focal length) often needs to be done with lenses of comparatively long focus in order to avoid an unpleasant perspective. In extreme cases, the available extensions can be varied by using extension or recessed tubes or boxes, enabling the lens flange to be placed at some distance in front of the camera front or within the bellows at some distance behind the front.

The baseboard must be fitted with a circular spirit level or with two tubular levels fixed at right angles to each other (T-level). When the camera has a swing back it is advisable to fix a plumb level to the back.

To allow of two subjects being taken on the two halves of a single plate, a groove is sometimes provided in the camera back. A piece of black

card can be slipped in to mask the half of the plate to be shielded whilst the other half is being exposed. To permit of stereoscopic pictures being taken on a single plate, some Continental cameras are fitted with a partition, made plated like a camera bellows, and guided between elastic cords. It is fastened to strips of wood, which in turn fit into recesses in the camera front and back.

The sizes in which cameras of the above pattern are most generally used for commercial photography and groups are whole-plate ($8\frac{1}{2} \times 6\frac{1}{2}$ in.), 10×8 in., and 12×10 in.

For the sake of reduced weight and bulk, the stand camera for amateur use is almost always made with taper bellows, as shown in Fig. 13.2. While less rigid than the square-bellows pattern and less satisfactory in affording proper parallelism of front and back, it embodies all the movements of the heavier model, and, in the case of some of them, to a greater degree. The size of this light-model camera which is by far the most widely sold and used is half-plate ($6\frac{1}{2} \times 4\frac{1}{2}$ in.). Larger sizes, e.g. $8\frac{1}{2} \times 6\frac{1}{2}$ in., are made, but the smaller, $4\frac{1}{2} \times 3\frac{1}{2}$ in., and particularly $3\frac{1}{2} \times 2\frac{1}{2}$ in., are now seldom used.

In the use of cameras for technical or architectural photography, it is an advantage to focus on a ground glass ruled in squares, which allow the operator to judge the verticality of upright lines and the size of particular parts of the subject. In America, some cameras are supplied with screens having such squares ruled or indicated by small dots. For landscape work it may suffice to rule on the screen two vertical and two horizontal lines dividing the sides into three equal parts, this plan serving to set out the strong and weak points of composition. The frame of the focusing screen is usually hinged to the camera.

It is advisable to sew tapes to the focusing cloth, so that it can be tied to the camera for work in the field; a further facility is one or two lead weights sewn into the corners of the cloth.

Mention may also be made of *panorama* cameras, which enable large groups of people or extended views to be taken. The camera, which is similar to a normal stand camera, turns on a vertical axis through the film surface, while a roll of film passes steadily across the focal plane.

156. The dark slides employed with portable stand cameras are generally of the double pattern, with single- or double-hinged shutters.

There are occasionally, at least in the $6\frac{1}{2} \times 4\frac{1}{2}$ in. size, single metal holders, as commonly used for hand cameras. By virtue of their construction, double slides with curtain shutters (as popular in France) afford a better protection of the plate against entrance of light whilst the slide is being carried or is in use, for both plates are completely enclosed by the two curtains, and when one of the plates is uncovered the curtain that is drawn back slides over the other, thus giving the plate not being exposed a double protection. Curtain slides should not be left lying about with the curtains withdrawn. The free edge of the blind has then nothing to hold it in place, and the very thin wood is liable to get out of shape, thus preventing the easy closing of the curtain. To ease the movement of the curtains in their grooves neither soap nor oil should be used; the proper lubricant is graphite (soft lead-pencil) or paraffin wax.

In slides with rigid shutters (solid or hinged) the light-tightness of the sliding shutter is ensured by an elastic packing of thick velvet pressed against the slide by springs. After long use, wear of the velvet may cause a falling-off in the efficiency of this light-trap, for which reason it is customary to protect the slides by carrying them under the focusing cloth and by keeping the cloth over the slide when drawing the shutter and making the exposure. Shutters of ebonite or thin wood sometimes let through their substance enough light to fog plates in a slide which is left exposed to full light for a considerable time. In addition, they are almost transparent to infra-red rays and therefore quite useless with infra-red-sensitized materials.

Double slides with rigid shutters are of two patterns. In current French makes a plate is introduced after drawing the corresponding shutter, the plate being kept within the rebates by turn-buttons. Similarly, holders for sheet film are usually designed to allow insertion of the film after the shutter has been withdrawn and the bottom of the slide hinged back to expose the ends of two slots in the side-pieces. In *book-form slides*, as commonly used in Great Britain and the United States, the frame is made in two parts hinged together. The plates are loaded without drawing the shutters or touching the film side. After one of the plates has been put in, a partition of blackened metal is turned down over it and secured by turn-buttons, and the whole is then folded over the other plate in its bed. This great convenience in loading is unfortunately sometimes offset by

a drawback; in the event of any warping of the wood used in the construction of the hinged frame, the light-tightness of the latter is pretty certain to suffer.

Numerous devices are employed for attaching the slides to the camera. The best are those in which sliding movement is avoided or reduced to a minimum, since there is the risk of the camera being shifted when the slide is being put in or taken out. All slides should be numbered on each side for subsequent identification of the negatives. If possible, a plate of ivory should be let in; on this, such notes as the brand of the plate, etc., can be written.

157. Tripods. For heavy apparatus it is unfortunately difficult to obtain stands which are sufficiently rigid for the long exposures that are sometimes needed and which are also comparatively light in weight and easy in manipulation. The legs are often too short and too flexible, and the top is often too small for adequate support of the camera.

In our opinion, the most practical model (despite its weight) is that known as the "double box," in which each leg consists of two wooden channel pieces sliding in each other, without any hinge or joint other than the one connecting each leg to the top. The bottom limb is solid and slides in the inner channel or "box." Set-screws enable the amount of slide to be fixed at any intermediate point desired. The best length of leg at full extension is 64-72 in. This height enables the lens to be at eye-level after the legs have been splayed out as desired. Tripods of this pattern are occasionally made for a much greater height. Passing mention should be made of the "ladder-stand," in which there are two sliding ladders with ledges, one for the photographer and the other for supporting a moveable platform on which the camera is placed. The view-point is thus raised 9 or 12 ft above the ground.

The tripod with detachable folding legs and metal top (which latter is sometimes incorporated in the camera itself as a turntable) takes longer to set up, and allows no variation of the height except by splaying the legs out more or less, which obviously gives little latitude. Light tripods with folding legs always tend to give at the joints and are therefore suitable only for cameras not larger than half-plate for outdoor use only, that is to say, usually with short exposures.

Telescopic metal tripods of fairly robust design have been introduced in recent years.

They are usually made of aluminium alloys and synthetic fibrous or plastic-impregnated materials. They are therefore reasonably light, though stronger, more rigid and more lasting than the wooden varieties. The better types have fairly large platform heads.

While manufacturers have apparently accepted the decisions of International Congresses as regards the standard of the thread of the tripod-screw, it is still sometimes found that a tripod-screw by one maker fails to fit the bush of a camera by another. The International Photographic Congress of 1889 (the decisions of which have not been accepted by English-speaking countries) adopted the screw known as " $\frac{1}{8}$ in. Whitworth." Most British and American cameras are fitted with " $\frac{1}{4}$ in. Whitworth" bushes.

Whatever the bellows extension used, the camera must be well balanced on the tripod. For this the camera should be fitted with several bushes arranged so that the one affording the greatest stability may be chosen.

The steel points with which tripod legs are shod tend to slip on pavings and polished parquet floors, and may damage carpets on which they are used. Slipping may be prevented by placing on the ground, in the shape of a three-pointed star, three chains joined to a ring in the centre; the points of the tripod are placed in the links at a suitable distance from the centre. The points may even be tied to each other with a piece of string. When working on a carpet, a three-pointed star made of thin lengths of wood is of great service. Each length is connected to the others at one end (this being the centre of the star), notches being provided near the free ends to receive the points of the tripod legs. This fitment is also exceedingly useful on pavings or polished floors, as it allows of the camera and stand being moved as a whole without disturbing any adjustment of the camera, as regards level, which has been made in composing the subject. The tripod points are sometimes fitted with rubber shoes hollowed in the form of suckers.

It is often advantageous and sometimes necessary to be able to tilt the camera without moving the tripod. This can be done by means of a tilting-head fixed to the tripod-top and to which the camera is secured. *Ball-and-socket heads* are suitable for light cameras, provided they are of robust design.

When photographing extended panoramas at successive exposures, the prints from which are

subsequently to be joined up, it is of service to be able to rotate the camera on a vertical axis through an equal angle each time. For this work a panoramic top is used; there are several commercial patterns intended particularly for light cameras.

158. Camera Cases. For carrying cameras and their accessories, use is generally made of waterproof cases of canvas or leather, lined with soft baize. Canvas cases intended for almost daily use should have the edges, folds and seams bound with leather. Strips of wood or metal studs must be fixed so as to project considerably from the bottom, in order to protect the latter when the case is put down on wet ground. Straps, particularly those for carrying the case on the back or slung across the shoulder, should be of real leather, and their width must be the greater as the weight is heavier. In the half-plate size, the camera, dark slides, and accessories, such as focusing cloth, are often all packed in one case. It is then advisable to have a long narrow case in which the camera and the slides are arranged side by side. For larger sizes it is best to have two cases, one for the camera and the other for the slides and accessories. In the case for the tripod, space should be provided for accessories such as the fitment for preventing the tripod points from slipping. Every camera case which is likely to be left in the care of others should be fitted with lock and key.

159. Hand-stand Cameras. A type of camera which occupies a mid-way position between those for use on a stand and those employed in the hand, is that which has been perfected by one or two makers of high-class cameras in England. In general design the camera resembles that shown in Fig. 13.2, but the back is made considerably deeper and the baseboard is solid, and hinged to the back, so that, in the closed position, all the moving parts are contained, as it were, in a box. These "hand-stand" cameras, as they are called, are fitted with finders and focusing scales for use in the hand, and with a bush for attachment to a tripod. As regards movements, such as extension, rise and fall of front, swing back, etc., they leave nothing to be desired, and the various models on the market in England are examples of design and workmanship of the most perfect kind. These cameras are chiefly used in the $4\frac{1}{2} \times 3\frac{1}{2}$ in. and 5×4 in. sizes, infrequently in half-plate size. In the case of at least one make this pattern of camera has been made in $3\frac{1}{2} \times 2\frac{1}{2}$ in. size.

160. Cameras for "While-you-wait" Photography. Brief reference may be made to the cameras (using ferrotype plates or post cards) with which is incorporated a box in which developing and fixing are done, the operator introducing his arms in sleeves of opaque material fixed to the camera, and secured round his arms by elastic bands. Others, for the production of real post cards, are fitted with a copying bench of simple construction, which folds down along the tripod while the photograph is being taken, and is then erected to hold the still wet paper negative when copying it on another post card as a positive.

161. Simultaneous Production of Negative and Positive Inside the Camera. An invention by E. H. Land in 1947 enables a semi-dry print, in contact with the negative, to be withdrawn by hand from the back of the camera within one minute of making the exposure. The principle is basically the same as that of the reversal-diffusion processes of A. Rott and E. Weyde (§ 883), though the application is different. In Land's invention, a light-sensitive paper is used in a camera having a normal lens, shutter, bellows and roll-holder. In the position normally occupied by the take-up spool is another roll of paper. This has a specially prepared non-light-sensitive layer and attached to it, at intervals corresponding to the distance between one exposure and the next, a number of pods containing a viscous processing solution. After each exposure, the film and paper are drawn off together face to face through a pair of pressure rollers in the back of the camera, which break the pod of solution and squeeze the two layers together with a layer of solution between. The sandwich can be cut off by a knife on the camera-back and peeled apart after about 50 seconds, the paper having a chemically-produced positive print on its surface, which needs no fixing or washing. This process is often described as "One-step."

162. Testing of Cameras. Newly acquired cameras need testing, and examination is also necessary at intervals with apparatus in service. The following points need attention—

Absence of play after the various parts have been set in position; parallelism of the front and back, tested with a square; the two parts require to be perpendicular to the long sides of the baseboard; agreement in register between the focusing screen and the dark slides; absence of reflections from the inside surfaces, which must be covered with a dead mat

varnish; and absolute light-tightness of the camera and slides.

In the case of small cameras the parallelism of the focusing screen and of the surface of the lens-board on which the lens flange rests may be tested directly as follows: On the points of three screws projecting from a board placed more or less horizontally, level a sheet of glass of a size closely similar to that of the focusing screen. After testing the horizontality of the glass by two cross-readings of a level, remove the glass and place the camera on the three screw-points, causing it to rest on its focusing screen. Then place the level in two cross positions on the lens flange or on the front cell of the lens, and see if the bubble indicates horizontality.

In order to check the register between the focusing screen and the dark slides, place a glass plate in the dark slide and fit the latter to the camera. Unscrew the lens and introduce a rod fitted with a sliding cross-piece that can be clamped. The tip of the rod is pressed against the surface of the plate, and the cross-piece is pushed against the lens flange and clamped at that point of its travel. The dark slide is then replaced by the focusing screen, and all that is necessary is to see that the tip of the rod touches the surface of the screen when the cross-piece is again placed against the flange. When the focusing screen and dark slides are fitted to the camera in the same manner, it suffices to see that they have the same register. To do this, use a thick wooden rule of perfectly flat surfaces, through the middle of which a screw has been placed so that it can be screwed in or out at will. The rule is placed across the front of the frame of the focusing screen and the screw is turned until its point just touches the ground surface. Plates are now put in the dark slides, and the rule is placed across the latter. If the register is correct, the point of the screw will touch the glass surface without pressing the plate back on the springs that hold it against the stops.

To see whether the camera is light-tight, take it into a dark or dimly-lit room and put an electric lamp inside it, first through the aperture in the lens board, a dark slide being in position, and then through the back of the camera, the lens being in place and capped. The opening through which the lamp has been introduced must be closed with the focusing cloth, and a careful inspection then made to see if any rays from the lamp can be detected escaping at the folds

and corners of the bellows or at the various joints.

The light-tightness of the slides can be tested only by photographic tests, viz. by loading them with plates (or, more cheaply, with bromide paper backed by a piece of card or a glass plate) and then exposing them for a considerable time to light (preferably sunlight) in all possible positions. The slide is then placed in position on the camera, the lens capped, the shutter withdrawn, and the camera left exposed to full light. Plates or papers subjected to the above treatment should not show more general fog than material taken directly from the packet

and developed at the same time, nor should they show local fog. Of course, the number of the slide will have been marked on each plate or sheet of paper, so that the defective slide may be identified and the fault located.

These tests must always be supplemented, and may even be replaced, by practical tests with the camera under normal conditions of use. As a rule, no new and untried instrument should be used for any work which is of special difficulty or cannot be repeated. It is especially inadvisable to start on any trip, still more so on any long journey, with a camera which has not been thoroughly tested.

CHAPTER XIV

HAND CAMERAS

163. General Notes. Owing to the great variety of hand cameras, a detailed description of them would demand more space than is warranted by the interest of such an account, and would to a large extent be a repetition of the catalogues of makers and dealers. We shall therefore restrict ourselves to some notes on the principal types in use at the present time, and to the description of some of the essential parts.

The first thing to emphasize is that a cheap camera, if handled intelligently, can yield quite as interesting and artistic photographs as those taken with a costly instrument. The superiority of the latter lies in the fact that it permits of a larger range of subjects being tackled, and allows of exposures being made under conditions where the owner of a cheap camera would have to refrain from taking a photograph. But the beginner stands a much better chance of success with a very simple camera, one with the least number of adjustments, than with one having many movements, some of which may be overlooked and others used wrongly.

Let us, however, note that some makers have recently developed, especially in the very small sizes (3×4 cm and under), various patterns embodying the automatic linkage of various components and various safety devices, leaving only a very few manipulations or adjustments to the operator, thus removing almost all possibility of faulty manipulation. Such devices include the coupling of a range-finder with the focusing adjustment, the correction of finder parallax (§ 169), the linkage of the shutter and iris diaphragm adjustments [either checked or actually governed by a photo-electric cell (§§ 351, 352) with correction when a light-filter carried on a swinging arm is placed before the lens], the automatic winding of exposed film, the linkage of this winding mechanism with the setting mechanism of the shutter, the locking of the shutter until the exposed film has been wound, the return to normal adjustments (e.g. closing of the shutter if it has been left open after exposure, return of the shutter to "instantaneous" marking, return of the iris to full aperture, removal of the light-filter from the lens) by the act of closing the camera, the automatic return

of the exposure counter to zero when the loading door is opened.

A prime consideration in the selection of cameras for use in hot and very damp climates, particularly in the tropics, is the choice of the material of which they are made. Hot, damp air tends to cause leather coverings and bellows to become detached, to warp the wood (and often to separate the glued joints), and to rust all fittings of iron or ordinary steel. Attacks by insects complete the destructive effect of damp air on leather bellows. Teak is one of the few woods that resist such climates and originally all cameras intended for use in the tropics were made of it, without the use of any leather covering. All parts must be screwed with brass screws. Many modern instruments, however, especially of very small sizes, are built entirely of bare or lacquered non-rusting metals or alloys, or with bodies moulded in materials which, like Bakelite, are not affected by the worst atmospheric conditions.

The shutters of the dark slides must never be of the curtain or hinged types, for the wooden strips may come unstuck. Single slides or changing boxes of almost rustless metal (stainless steel, nickel, German silver, aluminium) should be used exclusively. The shutter should preferably be of simple construction, without parts of iron or ordinary steel, and easy to repair in case it gets out of order.

164. Miniature Cameras. Since 1925 there has been a marked tendency to adopt smaller and smaller sizes, sometimes indeed beyond reasonable bounds (a camera has been made for 9×12 mm pictures on roll-film 16 mm wide!). This reduction in size, involving a considerable decrease in bulk and weight, has been very favourably received by amateurs and even by a fair number of professionals. It is indeed justified for various technical reasons.

On the one hand, progress in the manufacture of sensitive emulsions has made it possible to obtain without any great loss of speed images of fine grain (§ 196) lending themselves to much greater degrees of enlargement than previously possible. These advances were first applied to cinematographic film, hence the choice by several makers of standard 35-mm ciné film

for loading their cameras. Further, an appreciable saving results in the cost of sensitive material, the only negatives that are enlarged being, of course, those of some value. On the other hand, at the same relative lens aperture the depth of field increases as the focal length of the lens becomes shorter. It is thus possible to use lenses of very high aperture originally designed chiefly for the cinema industry, and obtainable only in short focal lengths.

The use on several of these cameras of interchangeable lenses covering a wide range of focal lengths (from 2·8 to 50 cm on a 24×36 mm camera, for instance) raised difficult problems in ensuring in all cases precision in the indications given by the view-finder and the range-finder. While it is possible to accept a fairly rough construction in the case of cameras giving pictures usable without enlargement, or with only a moderate degree of enlargement, miniature cameras must be of an extreme optical and mechanical precision. They are therefore usually fairly high in price. Such precision can best be obtained in a rigid, non-folding instrument (see also §§ 166 and 176).

As a rule no provision is made for a rising front in these cameras. It may therefore be necessary to tilt the camera when taking the photograph, the perspective being then corrected (§ 894) when enlarging.

165. The Chief Types of Hand Camera. Hand cameras may best be classified according to their general shape. We shall therefore divide hand cameras into rigid and folding patterns, without considering for the moment whether they are for use with plates or with films, especially as many can be used with all kinds of sensitive material.

Rigid cameras comprise box cameras of very simple construction intended for beginners, miniature cameras of high precision, and also the majority of reflex cameras (§ 176) and instruments derived from them.

Folding cameras are of three main types: (a) folding cameras that differ from the hand-stand cameras (§ 159) already described merely by their smaller dimensions and lighter weight, the hinged baseboard forming a protective cover when the camera is closed; (b) folding cameras with self-erecting front in which the lens board is automatically placed in position and returned into the camera body by means of jointed levers with spring catches, when the baseboard is opened and closed; (c) cameras usually known as Press cameras, without a protective cover,

the opening and closing of which resemble the movements in an opera hat with automatic locking in the extreme positions.

166. Rigid Cameras. Rigid cameras, bulky and heavy, especially when fitted with changing-boxes for 12 or 18 plates, are no longer used in medium sizes such as quarter-plate except for some special purposes. They are, however, widely used as "box-cameras" in $3\frac{1}{2} \times 2\frac{1}{2}$ and smaller sizes. Such equipment is intended for beginners and has the advantages of robust construction, simplicity in use and suitability for mass-production using cheap materials. It is unusual for such a box camera to be fitted with any but a low-aperture single lens and focusing movement and stops are therefore usually omitted. The latitude of modern roll-films is such that wide variations in exposure can be tolerated and the low aperture of the lens gives sufficient depth of field to cover most subjects.

Special types of rigid cameras are used in technical photography—for example, for identification portraits and for instrument dial recording.

Owing to the reflection of light which may always take place from the walls of box cameras, it is essential that the walls be a perfectly dead black. This is usually done by lining them with black cloth. In certain cameras not fitted with a rising front, particularly those for *aerial photography* and other patterns intended for photographic records of wild animals, all of which are usually fitted with lenses of very long focus illuminating a field much larger than the plate, protection against excessive light calls for a number of partitions (inside the camera), each with an aperture permitting only the useful rays to pass.

Cameras of the rigid type are the only ones suitable for use in an aeroplane, for no folding camera, however rigid it may seem, can resist the wind pressure acting on any object held outside the fuselage.

Miniature cameras using roll-film or ciné film are often fitted with a focal-plane shutter. This facilitates the interchange of various lenses as well as the linkage of the mechanism setting the shutter and that winding the exposed film. As the slit can travel very close to the sensitive surface the efficiency is excellent, and the use of a narrow slit gives the fast exposures demanded by the lenses of wide aperture.

The very slight depth of field of the large aperture lenses usually fitted to these cameras

and of the long-focus lenses sometimes employed on them would render illusory any focusing by judgment of distances, so that these cameras must be equipped with range-finders (§ 174), and in order to allow of photographing subjects in rapid motion it is necessary that the adjustment of the range-finder be coupled with the focusing adjustment, so as to avoid having to read off the distance in the range-finder and then set the focusing accordingly. In some cases, the camera mechanism is motorized, or otherwise arranged for operation at a high rate, in order to obtain series of pictures in sequence.

167. Folding Cameras. The essential advantages of folding cameras are their small bulk and their extreme lightness in spite of the moderately large picture they take—features which are sometimes obtained at the expense of convenience in handling and of rigidity after a period of use.

On cameras of this type the rising-front movements are generally limited, owing to the small size of the front and of the taper bellows. After raising (or lowering) the lens, it is necessary to centre it again before closing the camera. Closing must always be done gently, especially if one is not accustomed to this operation, for the space available within the casing is not great and if all the fittings (finder, release) do not occupy the exact position assigned to them, thus preventing the baseboard from closing, any force is bound to injure some parts.

With most folding plate cameras, the front must be pushed right back into the rear body on to runners that form the continuation of those on the baseboard. When the camera is opened, it is therefore necessary to pull the front out to the stops, which latter are usually at the "infinity" position. To do this, the front is drawn forward by finger grips on the carriage, these acting as clamps when the carriage is in position.

In the Press pull-out type, with stretcher-struts, the accordion-pleated bellows are sometimes replaced by a leather bag completely open at the extended position. The bellows are to be preferred, for the folds stop very oblique rays not used in forming the image, and are not likely to reflect them in the direction of the sensitive surface. When opening or closing these cameras the front and the back should be kept as parallel as possible in order to avoid bending the jointed levers. Cameras with folding levers are generally opened by a

slanting pull, but care must be taken that both the levers of a pair are working together, in order to prevent them from being bent.

As a rule these cameras allow of ample rise of front.

Hand cameras of the folding type have been available in sizes up to postcard ($5\frac{1}{2} \times 3\frac{1}{2}$ in.) or larger, but are not now generally made in sizes larger than $2\frac{1}{2} \times 4\frac{1}{4}$ in. Press cameras are made up to $6\frac{1}{2} \times 4\frac{3}{4}$ in.

168. Focusing of Hand Cameras. Except for folding plate cameras, which are less popular than formerly, hand cameras are not normally fitted with focusing screens and, except in the case of reflex cameras (§ 176), direct focusing on the subject is not possible. The extension of the camera must be brought to the proper distance by means of a scale (§ 87) graduated in distances of the subject.¹ It then suffices to bring the bevelled edge of the pointer on to the mark corresponding with the distance chosen.

With box cameras, focusing was done by moving the lens in a helical mounting (§ 112). This is also employed in some modern folding cameras, especially in Press cameras. A convenient variation, fitted to some of the smaller roll-film cameras allows the front cell of the lens only to rotate in this way (§ 110), thus focusing by optical adjustment. In the folding cameras with lazy-tongs and "scissor" levers the variation in extension is sometimes obtained by restricting more or less the opening of the levers by an adjustable stop linked to a bolt actuated by a screw fixed in the rear frame, the stop drawing with it the pointer placed against a focusing scale.²

The range of extension thus obtainable is very limited, so that these cameras are not suitable for use with lenses other than the one which the maker has fitted. At the most, they may be fitted with a rigid or folding rear extension, put in place of the dark slide, which is then fitted to the other end of the extension-piece. By this means it is possible to use one element of a convertible lens (§ 103) or lenses

¹ In cameras of British and American makes the scale in metres is replaced by one in feet. It is always well to test the scale of a new instrument.

² It would be a very good thing if the focusing scales of cameras intended for use at eye-level could be arranged so as to be visible from the back of the instrument, as commonly done on cinematograph cameras, with which the lever of the focusing mount is prolonged as a rod that projects beyond the top edge of the camera front.

of greater focal length than that fitted to the camera.

Cameras of the folding type, especially those with double extension, afford fair scope in focusing and allow of small objects being photographed. It is possible, within certain narrow limits, to fit other lenses, but if that is done, it will, as a rule, be impossible to close the camera without removing the lens.

169. Finders. In photographing a given subject with a camera held in the hand, the instrument must be fitted with a finder enabling the photographer to see whether the subject is or is not included in the useful field of the lens at the moment when the shutter is released.

The finder may be required to indicate only the direction in which the lens is pointed, but in almost all cases it is used to show exactly the limits of the field included. Let us hasten to add that in many of the cameras at present made the finder does not merit the confidence that one is led to place in it, so that the checking of the finder is a necessary precaution with any camera.

The problem of the finder is, moreover, a somewhat complex one if it is desired to solve it with desirable precision.

To begin with, we must note that except where the axis of the finder *coincides* with the axis of the lens, a condition that is fulfilled only in single-lens reflex cameras (§ 176), a finder which has been adjusted to indicate for distant objects the same field as that given by the lens, indicates, at very close distances, a field which is not in agreement with that of the camera, the difference increasing as the object is nearer and the axes of finder lens and camera lens are more widely separated. The differences between the image in the finder and the image in the camera are of the same order as the differences in the two images of a stereoscopic pair. In some modern cameras this "parallax error" is overcome by a mechanical link between the finder and the focusing movement which enables the field of view of the finder to correspond exactly with that of the lens at distances down to a few feet. Nevertheless it must be pointed out that this correspondence between the two fields will only be true for the main subject focused on. The position of both foreground and background in relation to the main subject will still not be the same for both images.

Another difficulty results from the rising and falling movements of the lens, which movements lose much of their value if agreement between the finder image and the camera image is not

attained, at least approximately, for all degrees of rise or fall of lens.

170. Ground-glass Finders. The simplest form of ground-glass finder is used only on cheap box cameras (without rising front) and consists of a miniature box camera fitted with a bi-convex lens of focus $\frac{3}{4}$ in. to 1 in. and provided with a tiny mirror at 45° , by which the image is reflected on to a horizontal piece of ground glass. This may be partially shielded against surrounding light by a hood which can be folded down over the ground glass when the finder is not in use. The image seen in the ground glass is very small and often dim owing to the small aperture necessary with an uncorrected lens.

A very well made pattern of this type of finder constitutes one of the two chambers of the twin-lens cameras described below (§ 177).

171. The Brilliant Erecting Finder. In many cameras of the folding type a finder similar to that just described is used, but the ground glass is replaced by a convergent lens with a mask cut so as to show the image obtained with the camera held vertically or horizontally. If the image is not formed exactly in the front nodal point of the convergent lens, it does not remain stationary in the mask of the finder when the eye (the correct position of which is not indicated in any way) is moved. The limits of the field are therefore very badly defined; all the more so as the image usually measures not more than about $\frac{1}{2} \times \frac{3}{4}$ in. It is true that the image is very bright, so bright, in fact, that the beginner is tempted to under-expose. To allow of use when the camera is used either way of the oblong format, these finders are mounted on a pivot to allow of their being turned over. As the camera can usually be closed only when the finder is in one position, closing may result in the bending of the finder bracket, and thus destroy the agreement between the field of the finder and that of the lens, assuming such agreement to have been present in the camera as sold.

A finder of this kind is only admissible in cameras which have no rising front. In various cameras some regard, at least to an approximate extent, has been paid to the rising front by causing the finder to tilt either by means of a cam fixed to the lens or by hand setting in correspondence with a scale indicating the various degrees of rise.

A non-decentring finder can be of some use if its field satisfactorily agrees with that of the lens. If a given point of the subject, such as the top of a monument, touches the upper

edge of the finder image, and if the camera lens is raised half an inch, we know that there will be a space of half an inch above the top of the monument in the photograph.

172. Direct-vision and Brilliant Finders. Perfect finders, at least when they are correctly mounted, consist of a frame of sheet metal or wire of the same size as the picture to be formed in the camera. These are fixed to the camera front (on which they can be turned down when not in use) so as to follow the lens in all its movements. This *frame finder* is completed by a sight, fixed near the back of the camera in a position such that a line passing through the sight to the centre of the frame is parallel with the optic axis of the lens when the latter is not decentred (Huillard, 1900). The parallax error with near objects can be corrected to a satisfactory degree in practice by mounting the sight on a sliding stem with a scale corresponding with the various distances of subject. The same result can be achieved by piercing the plate of the sight with several sight-holes, each corresponding with a given distance of the subject.

Instead of fixing the position of the eye relative to the frame by means of a sight (which is always troublesome to a wearer of glasses) a second frame may be used. This is similar to the first, but of smaller dimensions, and so placed that the straight lines joining corresponding corners of the two rectangles join together exactly at the sighting point. In this form, however, the finder no longer automatically follows the decentring of the lens. If the distance between the two frames is one-fifth of the focal distance (L. Benoist, 1897), the decentring of the larger frame must be one-fifth that of the lens. There is then no advantage in using a frame of the same size as the picture.

In order to retain the benefit of the automatic concordance of the field in the case of decentring, while reducing the size of the finder, the plan has been adopted of filling the space of the frame with a divergent lens. This arrangement is known as a *Newton finder*. The two axes, vertical and horizontal, of the frame are usually engraved on the divergent lens. The sight is sometimes fitted with a convergent lens. It is necessary¹ that the divergent lens used should

have a focal length equal to that of the objective, that its frame should have linear dimensions half those of the image recorded in the photograph, and that it should be placed at a distance from the sight equal to the focal length, the divergent lens being fixed on the lens front and the sight being fixed on the camera back (Gillon, 1900). This finder, unlike the one described above, does not show the same image as the lens when the extension differs greatly from the focal length.

Let us add that all the conditions given here, which ensure the perfection (for practical purposes) of the direct-vision brilliant finder, are by no means invariably fulfilled in all cameras fitted with finders of one or another of these patterns. It often happens that a given finder is fitted to very different cameras without any arrangement for compensating for the decentring of the lens. With brilliant finders of the divergent lens or plain-frame pattern, intended only to indicate the centre of the field of a camera not fitted with a rising front, the sighting eyepiece or pin is sometimes replaced by two crossed blades in planes parallel with the optic axis. These blades partially mask the frame unless the eye is placed in the same straight line along which they intersect each other.

In some cameras the divergent lens is fixed in a convenient position, and the eyepiece is replaced by a pin which follows the movements of the lens. The centre of the field is then indicated fairly correctly, whatever the amount of rise or fall of lens (except, of course, when the subject is quite close), but the margins of the field are not exactly shown. In some cameras not fitted with an eyepiece, the correct field is generally seen by placing the eye on the line joining the centre of the finder lens to the pin, the cheek and nose being pressed against the back of the camera. The angle of view can also be marked on two adjoining sides of the camera.

One distinct advantage of the direct-vision brilliant finders is that, in the case of moving objects, it is possible to watch with the naked eye the oncoming moving object in the direction which at the proper moment becomes the normal line of sight.

The use of direct-vision brilliant finders has increased in recent years and most of the better quality hand cameras are now fitted with one type or another, often built into the camera body and sometimes *parallax compensated* by a

¹ The proof of this fact would lead us too far. It is given by E. Wallon, in *Bull. Soc. Fr. Phot.*, 1901, pp. 121-131. It is easy to see if the finder has the required focal length by observing that a combination which is practically afocal is obtained by bringing the camera lens and the finder lens together.

mechanical link to the focusing mechanism or by setting a pointer to the distance.

173. Various Other Finders. Among the other finders used on some cameras may be mentioned the telescopes of the Galilean type (opera-glass) or of the astronomical type, either straight for use at eye-level or in an elbow form for use at waist-level, fitted with a graticule for indicating the centre and, in some cases, the margins of the field. The focusing of these telescopes is sometimes done by sliding a tube graduated in distances, the finder then acting as a range-finder.

Telescopic types of finders of fixed focus have become more popular in recent years, but in most instances suffer from the fact that their exit pupil is so close to the body that those wearing glasses cannot satisfactorily use them.

There is also another type of finder, commonly known as the *Albada* finder, which consists of a normal optical direct-vision finder, with the concave near surface of the front lens lightly silvered. The frame which holds the eyepiece of the finder, has on its front surface, facing the concave mirror, a rectangle or series of rectangles of suitable dimensions in white. On looking through the finder the subject is seen with the limits of the field of view clearly defined by the virtual image of the white lines, which appear in space apparently at the plane of the subject.

174. Range-finders. As far back as 1890 Dallmeyer proposed for this purpose two finders, one fixed and the other pivoting by the action of a cam linked with the focusing mechanism; the camera was correctly focused when the subject appeared in the centres of both finders. This arrangement has been simplified by using two optical systems, suitably separated from each other, the images of which are superimposed after one has been reflected on a mirror or prism which is turned through an angle by the focusing movement. In Fig. 14.1, the eye O sees directly an image of the subject aimed at, and another image of the same subject after two reflections in the mirrors M and M_1 . The mirror M is pivoted on an axis A and linked to a lever L held by a spring R in constant contact with a cam C coupled in some convenient manner to the lens-focusing mechanism. The mirror can therefore pass from the orientation M to the orientation M' when the lens, first focused on a very distant object P , is focused on a near object Q . The camera is correctly focused on a given subject when the

two superimposed images coincide in the portion covering that subject.

A colour filter is, as a rule, inserted in one of the optical paths so that the two images are more easily differentiated.

In some cases, the two mirrors are so designed that, instead of two superimposed images, one image is seen split in half horizontally. Each half corresponds to a part of one of the images referred to above and correct focus is achieved when the two halves exactly match to produce a single picture.

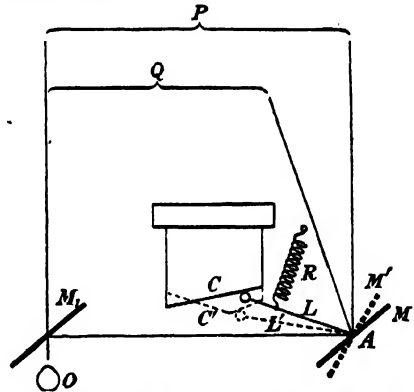


FIG 14.1. DIAGRAM OF A COUPLED RANGE-FINDER

The accuracy of focusing is all the greater as the base MM_1 is greater and as the subject is seen at apparently greater size. The range-finder, therefore, sometimes includes magnifying lenses. It can on occasion constitute a view-finder as well.

There are also on the market various types of coincidence range-finders, separate from the camera. In these, the orientation of the movable optical system is governed by a cam joined to an external knob bearing a distance scale. The distance of the subject being thus known, focusing is effected by means of the camera focusing scale.

In some cameras, particularly those with coupled rangefinders, the depth of field of the lens at any focusing distance is indicated by means of a *depth of field scale*. This may be on the lens mount so that it reads directly, when the lens is set, or as a separate guide on another part of the camera. In either case, it can refer to lenses of one focal length only and is calibrated in terms of distances and stop numbers.

175. Levels and Plumbs. It is desirable to be able to level the camera when holding it in the hand and sighting the subject, in order both to avoid the distortion which is produced if the sensitive surface is tilted and the reduction in the size resulting from the trimming which becomes necessary.

When the camera is held at waist-height, its level can be indicated by a circular spirit level or by two tubular air-bubble levels placed at right angles to each other; the levels must be placed near the finder or over it. The spirit

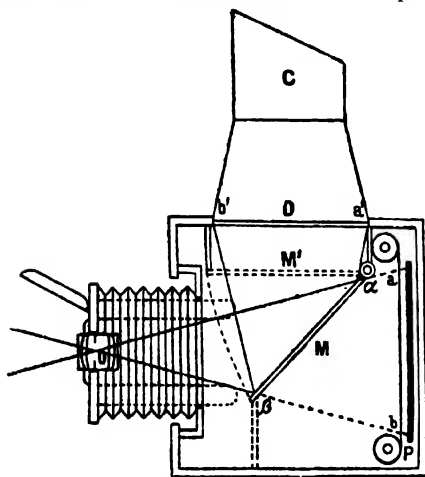


FIG. 14.2. REFLEX CAMERA

in the air-bubble levels tends to evaporate by the join between the concave glass that forms the cover and the metal body of the level. Levels have been made in which a steel ball rolls on a concave surface, but the ball is too mobile unless immersed in a viscous fluid such as a mixture of water and glycerine.

For sighting at eye-level, various plumbs or levels visible in the viewfinder, or plumbs on the outside of the camera, have been suggested. These are now rarely fitted and it is usually found in practice that the camera can, with care, be held sufficiently nearly level. Modern photographic practice tends to minimize the importance of the strict observance of verticals except with subject-matter which would normally be photographed with a stand camera.

176. Reflex Cameras. The reflex camera, first suggested by Sutton in 1861 and made in practical form by C. R. Smith in 1884, only became popular about 1900, and for a long time

was constructed only in a form similar to that of box cameras. At the present time there are folding models, made to meet the objection of bulk often advanced against this type of camera, unless of small size. The principle of these cameras is shown in the sectional diagram (Fig. 14.2). When the camera is not in use, the plate *P* is covered by a focal plane shutter. Some reflex cameras are fitted with a lens shutter, the mirror protecting the sensitive surface sufficiently while the image is being sighted. The rays from the lens *O* fall on a mirror arranged at 45° in the plane bisecting the angle between the sensitive surface and the ground glass *D*, which latter is shielded from surrounding light by the hood *C*. In these conditions, if the lens is in such a position that a sharp image is formed on the sensitive surface *ab*, the reflected image *a'b'* will also be sharp on the ground glass and vice versa; the image on the screen is the right way up, although the wrong way round.

As reflex cameras cannot be used conveniently except in their normal upright position, they are usually fitted with a square reversing or revolving back, which carries the dark slide in one or other position. In some of the more highly priced models the rotation of the back automatically operates a mask, which thus shows an upright or oblong picture on the ground glass. Otherwise the latter is clearly marked with the edges of the upright or oblong picture. There is usually only a vertical rise and fall of front and this only to a limited extent. The usual sizes of reflex cameras range from $3\frac{1}{2} \times 2\frac{1}{2}$ in. to $6\frac{1}{2} \times 4\frac{1}{2}$ in. As the camera is hardly ever carried in a case, the lens is protected by a rigid flap of wood or metal, which can be set at various angles and serves as a sky shade.

The camera, which is often hung from the neck by a strap, is held in both hands, one actuating the focusing knob while the subject is being followed on the screen. When it is judged that the favourable moment has arrived for taking the photograph, the release which operates the mirror is pressed. The mirror rises to the position *M'* against stops, thus effecting a light-tight closure of the upper portion of the space within the camera. The focal-plane shutter is then immediately released which uncovers the sensitive surface for a time fixed by the speed setting.

To set the camera for taking another photograph the mirror is allowed to drop and the shutter set again, either automatically or by hand.

An ordinary mirror, silvered beneath the glass, would produce a double image on the focusing screen, and cannot therefore be employed in a good instrument, as the finest focusing is not possible. The silvering requires to be on the surface of the glass presented to the lens, and is usually protected by a very thin coat of varnish, which does not interfere with its optical performance. To avoid occasion for the re-silvering of the mirror, care must be taken not to finger or rub the surface. Any dust that may settle on it should be removed very gently by means of a clean and perfectly dry brush. On some cameras built recently a mirror of stainless steel has been fitted.

The advantages of a reflex camera are obvious. The image is seen on the screen until just before the exposure is made and is of the same size and has the same limits as the picture taken, whatever the camera extension and degree of use of the rising front. There is no finder which affords this facility. Focusing is more easily done at the full aperture of the lens, but it would be contrary to the very principle of the reflex to require the operator to turn the camera round to set the lens aperture for the necessary depth of field. Some makers have provided a special form of iris diaphragm for this contingency. The lever of the iris is kept constantly pressed by a spring which tends to close the diaphragm. This lever is held against stops which can be placed at any desired point of the diaphragm scale. For focusing, the lens is set at full aperture, the lever being held by a catch which is freed by the release of the mirror and thus brings the smaller stop into operation for the exposure.

The range in extension is sufficient to allow of some latitude in the choice of a lens, an advantage that is offered by scarcely any other hand camera. This latitude is increased by the fitting of an extension piece to the camera front (some cameras are specially built for lenses of very great focal length), but the use of the reflex is incompatible with the use of wide-angle lenses on account of the necessity of leaving a clear space for the passage of the mirror. In the case of a $3\frac{1}{2} \times 4\frac{1}{4}$ in. square reflex, the shortest focal length which can be used is 6 in., or a little less if the camera is built for oblong pictures only. The chief objection to the reflex camera is the practical impossibility of using it at eye-level. To meet this difficulty, some makers fit a sighting hood arranged horizontally above the ground glass and fitted with a mirror

at 45° to the latter. The picture on the ground glass may thus be seen in the mirror.

It is curious to note that in the minds of many amateur and professional photographers the reflex is regarded as specially intended for Press photographers and, generally, for the photography of rapidly-moving objects. Yet specialists in these two branches of work consider it unsuitable, and prefer to use cameras of the folding focal-plane type.

Nevertheless, the reflex is the best hand camera for the great majority of photographic work, artistic and scientific and especially for the photography of animal subjects. Its only disadvantages are its price, necessarily high in view of the complexity of its mechanism, and—in the case of box models such as the one in Fig. 14.2—its bulk and weight.

177. Twin-lens Cameras. The method of focusing a rigid or folding camera by means of an auxiliary lens of the same focal length as the main lens, but less fully corrected, was used in the past, but was abandoned almost at once as being very cumbersome at a period when plates of size under 7×5 in. were scarcely used. This idea has been successfully revived in some film cameras of miniature size, in order to give the user the same facilities that a reflex would give, a reflex being difficult to build with such short focal lengths as are usually employed. The auxiliary camera is then of the reflex type, but with a fixed mirror. For sighting at eye level a mirror that can be lifted has, however, been used, the ground glass and its hood being then placed on the back of the camera.

The differences in the framing of the two images are then compensated for by decentring or swinging the auxiliary lens, or by moving a mask under the ground glass, all such adjustments being actuated by the focusing movement so as to ensure the coincidence of the fields included in the plane of space-object conjugate to the plane of the sensitive emulsion.

In some of the cheaper types of twin-lens reflex, no focusing movement or stops are provided on the auxiliary lens and the viewing assembly therefore becomes, in effect, merely a full-size ground-glass viewfinder.

To facilitate the examination of the image the customary ground glass is sometimes replaced by a plano-convex lens of which the plane surface is finely matted, the lens then acting as a collecting lens (the marginal rays being thus turned towards the observer), and as a magnifier. More recently the marginal illumination on

the viewing screen of twin-lens reflex cameras has been improved by the introduction of a very thin Fresnel lens just beneath the screen. A focusing magnifier is sometimes carried by a movable arm inside the hood.

To reduce the depth of field of the auxiliary lens and thus permit of more accurate focusing, this lens is sometimes of a relative aperture greater than that of the main lens, or it may even be of greater focal length in spite of the mechanical difficulties presented by the linkage of the focusing movements of the two lenses.

178. Sensitive Material. Hand cameras can be used with plates (glass support), films (transparent flexible support), or sensitized paper (§ 239). The films may be in long strips (roll film) or in cut sizes. By far the greatest number now made are roll-film cameras.

Various attempts, attended with little success, have been made to supply plates packed in such a manner that the packet can be placed in the camera in full daylight. Plates are usually carried in dark slides for one or two plates, which are detachable and may be purchased in any number required. In the past, changing boxes for 6, 12, or 18 plates have been used in place of plate-holders but these are now rarely seen.

Films cut in sizes are supplied either for use like glass plates, in the same slides or boxes, or in special packings called *film packs*. A film pack is itself a changing box for 12 films, and only needs placing in a special adapter (film-pack adapter) interchangeable with the slides or boxes. In order to fit cut sheet films in some dark-slides intended for plates, *cut-film sheaths* or *adapters* are required.

Roll-film, formerly used in roll-holders of somewhat complicated construction, is held inside a roll of opaque paper which, in conjunction with the flanges of the spool on which the film is wound, affords full protection against light, thus permitting of loading and unloading the holder in daylight. This roll bears numbered marks visible from outside through a window of red celluloid. To reduce the price of the cameras, and also to compel to a certain extent their purchasers to use roll film exclusively, the detachable roll-holder was largely replaced by a film magazine built in as an integral part of the camera. Some roll-film cameras, however, can be supplied with special backs adapted to allow the use of dark slides for plates, while roll-holders are still obtainable for use in some cameras intended for plates.

When using panchromatic film in a roll-film camera the red window must be covered except during the time strictly necessary, after each exposure, to centre the next number in the window. Cameras of recent construction are fitted for this purpose with a flap kept closed by a spring (sometimes the flap only opens when the winding key is being turned). In the absence of such a flap, the outside of the window should be covered with a piece of opaque adhesive material, usually supplied with each spool of panchromatic film. Various arrangements of multiple windows permit in some cameras (fitted with removable masks) the use of roll-film for picture sizes other than the normal one.

The methods of loading the various slides and changing boxes differ to such an extent on the cameras of various makers that a detailed description cannot be given. The instructions sent out with each camera should be followed.

179. Single Metal Slides. Although double dark slides with curtain shutters are used with some hand cameras (§ 156), it is far more usual to employ single metal slides, made of stamped sheet steel or nickel, with a metal pull-out shutter, such slides being cheaper, lighter, and more compact. All these slides should, of course, be numbered for identification of the exposures.

Dark slides are used in preference to a plate or sheet-film magazine inside the camera to ensure the avoidance of any risk of jamming and to introduce the possibility of taking a selection of plates of various kinds or for various purposes. Also, as the camera is loaded with only the one plate, it is less heavy and cumbersome to use.

In some cases confusion between slides containing unexposed plates with those containing exposed plates may be avoided by turning the other side of the shutter outwards when replacing it after exposure. Mention may also be made of the various devices (coloured tags, catches which automatically lock the shutter when it is replaced after exposure) for preventing two exposures on one plate.

It is usually possible by means of carriers to use in these slides plates of size smaller than the normal. Cut films and paper can also be used by placing them in holders, of which various patterns exist (book-form, sheath, or stretcher) or, in some cases, by the use of a metal sheet covered with a suitable adhesive.

This review of holders for plates would not

be complete without a reference to the special slides or adapters intended for loading in daylight by the use of envelopes of stout opaque paper each containing one plate. The envelope is opened when the shutter of the adapter is drawn and closed when it is pushed back. In England this envelope system was at one time widely used by Press photographers.

180. Roll-film Cameras. It is to George Eastman (1889) that the invention of the roll-film holder and of the appropriate packing of the film is due. The forms originated by him differ little from those in use at the present day.

Two spools, one empty (*B*) and the other (*B'*) with film wound on it (Fig. 14.3), are placed on either side of the camera proper, their end disc pieces being fitted to pivots, one of which can be turned from the outside, whilst both pairs act as axes of rotation. After taking off the detachable cover *CC*, the spools are placed in position on their pivots, noting that the two

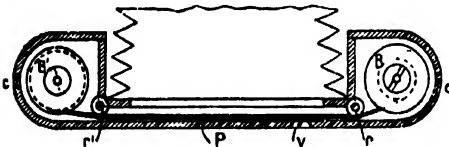


FIG. 14.3. ROLL-FILM CHANGING MECHANISM

spools must be placed inversely to each other, the groove in one of the discs of the spool placed in *B* having to fit the pin of a winding-key operated from outside the camera. Four to six inches of the black or red paper wound on the spool are unwound and the taper end inserted in the slot of the empty spool at *B*. A few turns of the key are given to wind the paper tightly round spool *B*, and then the back *CC* is replaced. Some fifteen half-turns of the key are then given, the paper passing from *B'* to *B*, and moving without friction over the rollers *rr'*. As soon as the film, carried by the paper, reaches the field of the lens, a warning sign appears in the red window *V*, and is soon followed by the figure 1, showing that the film is in position for the first exposure. After making the exposure the key is turned until the figure 2 appears, and so on. After taking the last photograph (the spools are usually for 6, 8, 12 or 16 exposures, according to the size of the pictures), the key is given about fifteen half-turns, and the cover is then taken off. The winding of the paper is then continued, pressing the fingers *very gently* on the spool to

prevent the paper from uncoiling when it is no longer kept under tension by the springs which brake the supply spool. The spool is then removed and sealed with the gummed strip attached to the end of the black or red paper.

181. The spools with wooden centres, on which the metal flanges were forced by pressure, are usually replaced in the current sizes by all-metal spools which are of more accurate manufacture and often of smaller diameter. The space between the flanges must permit the rolling up of the film and its wrapping paper, but without sufficient play to admit light. The slit in which the tongue of the paper is engaged must be exactly standardized. The spool must be sufficiently rigid to resist deformation by torsion of its axis which would result in unequal tension of the film and sometimes cause scratches on the emulsion. When travelling from one spool to the other the film slides on the wrapping paper, and for this reason it is secured only by one of its ends. In spite of this sliding a film with paper backing can never be perfectly stretched in the image plane. For this reason it has been necessary in very small sizes, i.e. such as need considerable enlargement, to use naked film (§ 184).

When a folding camera has been closed and then opened with the film in position for the next view, it is advisable to stretch the film by turning the winding key slightly, as the film may have been slackened by the air eddies inside the camera.

182. A very ingenious device has been used for identifying the negatives as they are being taken (*autographic* film and cameras, H. J. Gaisman, 1913). Instead of a single opaque paper wrapping for the film, two papers are used, one a "carbon" paper, as used in duplicate books, and the other a thin red paper. Neither of these is completely opaque alone. The back of the camera is provided, a little beyond the edge of the picture, with a narrow slot which is kept covered by a spring flap. Following an exposure, the flap is raised and the desired note is made with a metal stylus, attached to the camera. An ordinary lead pencil, not too finely pointed, may be used instead of the stylus, but never a copying pencil, as the colour of the latter may come off on the sensitive surface of the next turn of film. No mark appears on the surface of the red paper, but the coating on the underlying carbon paper is removed where the stylus has pressed on it. The slight play between the two papers enables the light, diffused by the red paper, to act on

the film through the inscription thus stencilled on the carbon paper, the camera being pointed to the sky (but not to the sun) for this purpose with the flap open. The flap is then closed and secured. The special roll-films required for this system are no longer manufactured. It is interesting to note, however, that a somewhat poor image of the writing can be obtained on ordinary roll-film material purely by the pressure exerted by the stylus, which enables some silver halide grains to be developed.

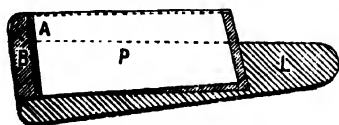


FIG. 14.4. FILM AND TAB OF FILM PACK

183. Various improvements in the construction of film cameras have been suggested, and some of them have been applied, without, however, coming into general use. To ensure the flatness of the film, which is especially necessary with lenses of large aperture, film cameras are made in which the film is pressed against a sheet of glass by a plate, the pressure of which is relaxed during the time that the exposed film is being changed. Films kept for long in a very dry atmosphere will occasionally become crinkled at the edges and then fail to give sharp pictures, unless the lens is used with a very small stop. To permit focusing on a ground-glass screen, which is impossible with the usual cameras, the film-holding part of the camera has been made separate from the rest, or attached to it by a hinge, a shutter being fitted to the film-holder part to allow of detachment. To simplify the changing of the exposed section it has been suggested that the turning of the key should be replaced by a pull on a cord instantly wound back by a spring, or by a threaded rod protruding from a tube like the mechanism of an Archimedeian drill, and causing the rotation of the take-up spool. Various devices have been evolved for using a camera with spools of size smaller than the normal one (junction pieces for the pivots and metal masks restricting the length of the exposed film).

Reference must lastly be made to the common use of *adapters for dark slides for plates*, interchangeable with the ordinary back, or attachable to the film camera after the ordinary back has been removed. Some adapters bring the sensi-

tive surface of the plate into the plane normally occupied by the sensitive surface of the film, and thus permit of the usual focusing scales being employed. With most adapters, however, a correction of the focusing is necessary unless the camera is fitted with a second focusing scale, engraved in a different colour or clearly marked "Plates."

184. The necessity to use bare film in miniature cameras fitted with large aperture lenses in order to avoid defective flatness due to the



FIG. 14.5. CONSTRUCTION OF FILM PACK

sliding of the film on the paper (§ 180) has led, in order to facilitate the winding of the film and the working of a counter, to the adoption of 35-mm ciné film with two marginal rows of perforations, leaving between them a usable space of 25 mm width.

This film is usually supplied for 20 or 36 exposures 24×36 mm (the length of 36 mm is equal to six times the pitch of the perforations) in a special cassette in lengths of 2 ft 6 in. or 5 ft of which about 6 in. are sacrificed at the free end of the strip as the leader, suitably tapered for attachment in the camera in daylight. To avoid losing a similar length at the other end the exposed film is not wound completely on to a second spool but into a receptacle from which, after all the exposures have been made and before opening the camera, it is returned to the charger by rotation of a milled knob turning the core of the cassette. To make this return possible the interior end of the film strip must not be detached from the core, as would happen if, after the final exposure, an attempt were made to overcome the resistance then felt to unwinding. If this accident should occur the film cannot be returned to the charger until the camera has been opened in a dark room.

In miniature cameras of this type, an attempt is often made to make the camera semi-automatic. The film-winding mechanism may set the shutter and, in such cases, an interlock is usually provided to prevent either unintentional double exposures or blank frames.

185. **Film-packs.** The cut-film packing forming a changing box for the films it contains

still retains the name of "film pack" under which it was first issued in 1903 by the Rochester Optical Co. To avoid abrasion of the sensitive surface (§ 200) during changing, the emulsion of these films is covered with a very thin (0.004 mm) supercoat of hardened gelatine.

Each of the 12 films *P* (Fig. 14.4) is attached (on one of its short sides) by an adhesive strip *A* to a long band *B* of lacquered opaque paper ending in a tab *L*. The 12 films (only two are shown in Fig. 14.5) are placed in a pile in a thin sheet metal box with a fixed interior partition, which is extended as a kind of metal gutter, and with a rectangular cut-out within which the film is exposed. The tabs of the films are led round the gutter and project from the casing. They are covered with a band (of the same paper) which forms the safety cover of the pack. Between the fixed partition and the pack of films there is a plate of thin metal. It is held away from the partition by springs and presses the safety cover against the cut-out and the films against the safety cover. Strips of felt press the tabs together at the point where they emerge from the casing, and another strip of felt presses the curved portion of the paper bands against the convex surface of the gutter.

In use, the pack is placed in an adapter interchangeable with the dark slides of the camera. This having been done, the rear tab (the tab of the safety cover) is pulled so as to uncover the first film. The pull must be steady and gentle; a violent, sudden pull may tear the tabs before the films have been changed. After the first film has been exposed it is transferred to the rear compartment by pulling the tab marked No. 1 until there is felt a resistance, due to the extra thickness of the film and adhesive strip. The protruding length of the band of black paper is then torn off by pulling it sideways against the metal edge of the adapter. The changed film remains attached to a sheet of black paper bearing the number 1, thus allowing of the negatives being identified. The second film is thus in place ready for exposure. After it has been exposed it is changed by pulling tab No. 2, and so on. When the twelfth film has been changed the pressure plate is pressed against the cut-out and closes it. The pack can then be removed from the adapter in daylight and replaced by a fresh one. After removing the exposed films from the metal box the latter is thrown away. The frail construction of film packs renders them very liable to be bent by any abnormal pressure, and

this may lead to difficulties in changing or to the occurrence of streaks of fog, particularly along the edges. A film pack should never be carried in the pocket except in the cardboard box in which it is sold, and care should be taken not to crush it in trunks or suit-cases in which it may be packed. Only a few manufacturers make film packs available under present-day conditions.

186. Tripods and Pocket-supports for Hand Cameras. An exposure of 1/10 second is usually the longest that can be given with the camera held in the hand without risk of movement due to the involuntary movements of the body. While some cameras can be placed level on a table or a window-sill, it is not always possible to find a steady support or a wall conveniently placed against which to hold it. If the user is not to be greatly limited in his work with a hand camera, an indispensable accessory is a tripod, or at any rate one of the many patterns of pocket accessories by which the camera may be fixed to a very large number of natural supports. For the purpose of steadying a camera held in the hands it has been suggested that the instrument be held in a state of tension by securing a long strip to it and keeping this latter anchored under the operator's foot.

A hand camera must therefore have, on at least one side, a bush of the standard Continental screw-thread (§ 157), or the Anglo-American thread. Nearly all metal tripods are fitted with the English screw and with an adapter with an interior (female) thread of the English standard and the Continental thread outside. If a camera with the Continental thread is being used, it is well to solder this adapter on and so avoid losing it. Continental cameras often have a similar adapter fitted into the bush, which should be similarly soldered if an English tripod is in use. There is a growing tendency to fit one bush only and to rely upon a ball-and-socket head for pictures in the other format.

It is of course not possible to consider the use of the solid wooden tripods made for portable professional apparatus, for such a tripod would be heavier and more bulky than the camera itself. Nearly always telescopic metal tripods are used, in which the legs are divided into sections sliding or folding one in another. The rigidity of an extended leg leaves more to be desired, as the diameter of the tubes is smaller and the number of sections is increased with the object of reducing the length for carrying. Weight for weight, it is preferable to use tripods

with aluminium tubes of large diameter fitted with brass slide-sleeves rather than tripods with slender brass tubes. Tubes of triangular section can be quite sturdy without the total section of the tripod being too large, as the legs fit closely against each other. The length of the legs is regulated by drawing out a greater or less number of sections. As a rule, the sections lock automatically as each is fully extended (some tripods with cylindrical legs have a bayonet catch), and for closing all that usually needs to be done is to press one catch on each leg, the whole leg then collapsing on applying a fairly sharp push.

Some manufacturers supply tripods which can be taken to pieces and spare parts obtained to replace any that become worn, but metal stands which do not bear a manufacturer's mark are usually irreparable.

Tripods have been supplied, though not to a large extent, with a screw ring around the head by means of which the degree of opening of the legs can be regulated and the tripod can thus be prevented from slipping. It has also been suggested that the head should be fitted with a thick disc of felt or rubber, the elasticity of which allows the camera to rotate without having to turn the whole metal tripod.

There can also be obtained commercially ball-and-socket heads, usually of too light a construction, and panoramic heads for the same purposes as with professional cameras (§ 157).

The pocket supports have their uses. They usually comprise a base, with screw, for the camera, and a ball-and-socket uniting the base to a kind of joiner's clamp. The latter enables the fitment to be fixed to the back of a chair, handlebar of a cycle, fence, or door frame. In some cases the support can be fixed to a tree-trunk or mast by a steel ribbon or chain which can be drawn tight by an eccentric fastening.

187. Tests of a Hand Camera. In addition to the tests already described (§ 162) for professional cameras, especially as regards the coincidences of the planes of the focusing screen and of the sensitive surface, the examination of the lens (§ 115) and of the shutter (§ 146), which are usually integral parts of the camera, there is need, in the case of a hand camera, to make the following tests.

In cameras with tapering bellows, see that the picture is not cut off by the bellows, especially when the rising front is used to any extent.

In all cameras fitted with a focusing scale, verify, either by examination of the image on the screen, or, better, by a practical photographic test, that test-objects such as a sheet of printed matter facing the camera, placed at the various distances marked on the scale, are really rendered sharply.

In all cameras fitted with finders it is necessary to see that there is at least a reasonable degree of agreement between the picture in the finder and that in the camera. If necessary, a finder which shows too much subject must be masked with bands of gummed black paper or with black varnish. Of the two evils, it is better that the finder should show less subject than the camera records, since the negative can be enlarged if the image is smaller than is desirable.

It is also well to see if it is possible to fit a colour filter to the lens if required, and if the thread of the tripod screw fits that of the bushes on the camera so as to allow of the latter being properly fixed on the tripod.

188. Care of the Camera. A camera treated properly can give long service while retaining all its original qualities, but any wrong handling, and any attempt to force it to open or close without loosening the catches or replacing in position the various parts, may result in serious damage.

Parts where there is friction (baseboard runners, grooves of dark slides and shutters therefor, etc.) must be lubricated from time to time, preferably with graphite, e.g. with a carpenter's pencil at an angle, and with which it is easy to apply a very thin film of graphite, which considerably reduces the risk of premature wear.

A photographic camera must never be left in a damp place, for the woodwork may swell, the leather covering may come unstuck, and the metal parts may rust or become covered with verdigris. If a camera has been exposed to rain and particularly to sea-water, it should be wiped with as little delay as possible. It should then be placed in a dry place, until the bellows are quite dry. A piece of waterproof cloth enables the camera to be properly protected when necessary. No less important than the avoidance of a fall or sudden knock is that of constant vibration which in time causes the loss of screws fixing the parts together. A camera case should not be attached rigidly to the handlebar of a cycle, nor put on the floor of a car. From time to time a polish composed of wax and turpentine should be rubbed on the woodwork and leather covering and metal parts should be rubbed with a rag very slightly

greased with petroleum jelly. Bellows of varnished leather must never be greased. They should be dusted from time to time with talc and the excess then wiped off. This prevents the folds from sticking together.

All the interior parts should be cleaned fairly frequently with a brush and dry rag.

Special precautions must be taken with dark slides and steel sheaths. They must never be left in a dark-room, where it is always somewhat damp. When in process of loading and unloading they should be placed on a perfectly dry table, secured from risk of splashings of liquid. Blackened steel rusts very easily, and the rust comes off in flakes and is likely to adhere to the sensitive surfaces and cause spots, for which there is no remedy. When slides and sheaths

are likely to remain unused for a long period it is well to grease them very slightly with petroleum jelly, but they must be freed from the grease with a dry rag before using them again. These accessories are easy to damage if clumsily handled, and a dark slide or shutter that has been bent is usually not light-tight, while a bent sheath is likely to scratch the emulsion surface of the plate behind it.

A camera should never be left in a cupboard except in its case. The lens should be cleaned (§ 116) from time to time, but not to an undue extent, the surfaces being liable to injury as the result of improper cleaning. Finally, it should be remembered that the shutter must never be oiled, and that it must not be taken to pieces except by an expert.

PART 3

PRODUCTION OF NEGATIVES

CHAPTER XV

THE NEGATIVE : GENERAL REMARKS ON PHOTOGRAPHIC NEGATIVE PROCESSES

189. The Wet Collodion Process. Of the many different photographic processes which were practised before the introduction of modern gelatine-silver bromide plates and films, the only one which is still commonly used commercially (photo-mechanical reproductions, copying originals for enlargement, etc.) is the *wet collodion process*. In this process each sensitive plate is prepared by the user immediately before it is required (the plate not being dried until the various stages of the process are finished) by coating a sheet of glass with a layer of collodion containing a suitable mixture of bromides and iodides. As soon as the collodion is set, the plate is immersed in a solution of silver nitrate, and by interaction between the silver nitrate and the ammonium and cadmium bromides and iodides, silver bromide and silver iodide are formed in the collodion film whilst the ammonium and cadmium nitrates go into solution. After draining, the plate is exposed in the camera and taken to the dark-room. However long the exposure given to the plate, no visible image appears. The image is described as *latent* from the Latin *latens*, meaning hidden. It can be rendered visible only by the process of *development*, i.e. by treatment of the plate with a solution containing reducing agents (combining readily with oxygen), e.g. a solution of ferrous sulphate, with the addition of an acid to retard the process and render it more regular. The developer reduces the silver nitrate impregnated in the film to silver which is deposited in minute particles only at those points on the plate which have been exposed to light, the amount of silver deposit increasing with the amount of exposure, thus giving an image. This method of development by precipitation of the silver contained in the developer is always spoken of as *physical development*. After rinsing, the image is freed from the silver salts which served as a temporary support for it by treating it with a solvent of silver iodide, e.g. a solution of sodium cyanide. This process is called *fixing*. The silver deposit

viewed by transmitted light, is more or less opaque; viewed by reflection, especially in front of a dark background, it appears white, as do almost all images obtained by physical development. This property was formerly used for obtaining direct positives, thus imitating to some extent the Daguerreotype, the forerunner of the ferrotype portraits of travelling photographers.

All these processes, including fixation, must be carried out in yellow light.

Under otherwise equal conditions, wet collodion plates require some twenty times as much exposure as a gelatine-silver bromide material of lowest speed. The advantages of the wet collodion method are the high resolving power, the extreme rapidity of the whole operation, and the ease with which the emulsion can be stripped from its support.

190. The Gelatine-Bromide Process. The manufacture of gelatine-silver bromide plates, films, and papers is exclusively an industrial process. The emulsion of which the sensitive coating is made is obtained by mixing under suitable conditions, in the presence of gelatine, solutions of silver nitrate with bromide and a small amount of iodide of potassium. In this way minute crystalline grains of silver bromide, with a little iodide, are formed. After washing so as to remove the residual soluble salts, the emulsion which is a milky suspension of the crystalline grains in gelatine is coated on the appropriate support and put on the market after sorting, cutting-up, and suitable packing.

When such an emulsion is exposed to light, no change is directly observable, except perhaps that after a fairly long time it darkens slightly from its original yellowish appearance. Light, however, will form a latent image in a silver bromide-gelatine emulsion just as it does in a collodion emulsion.

The resulting negative image appears only when the emulsion is treated with a complex solution, the developer. The essential con-

stituent; the developing agent itself, is a reducing substance chosen from amongst a fairly limited number of chemicals. With silver bromide emulsions the process known as *chemical development* is used almost exclusively, the image being formed by reducing directly to silver the silver halide grains affected by light.

The silver obtained by chemical development is usually in the form of minute mat black particles, the agglomerations of which retain to some extent the appearance of the original emulsion crystals, but have a spongy structure comparable with that of coke. After rinsing, the excess of silver halides is removed from the image since they reduce the contrast and are unstable. This process of *fixation* is carried out in a solvent for silver bromide which is generally a solution of sodium thiosulphate (hypo). The negative thus obtained is then washed to remove the soluble salts, and finally dried.

Instead of dissolving out the silver bromide whilst allowing the reduced metallic silver to remain, the silver may be dissolved out and the silver bromide left. When the remaining silver bromide is reduced a *direct positive* image is obtained, i.e. an image in which the density distribution is the inverse of that in the normal negative. In this way a direct positive is obtained. This, however, is not as a rule of good quality, unless special emulsions or more refined techniques are used.

Silver bromide-gelatine emulsions may be *physically developed* either before or after fixing, but as the coating does not contain any soluble silver salts, a solution of silver nitrate must be added to the developer.

Lastly, it should be mentioned that development and fixation can be carried out simultane-

ously, by mixing a developer and sodium thiosulphate in suitable proportions.

This procedure is, however, of little practical importance.

The processes mentioned above must obviously be carried out in the absence of all light which can act on the sensitive materials used. It will be seen later that a very weak orange-red or green light is generally employed.

It is possible, however, to *desensitize* the emulsion, after exposure in the camera, by treatment in a very dilute solution of certain substances, coloured or non-coloured, the actual coloration, however, playing no part. A desensitized emulsion may be developed in ample yellow light, or even in weak white light.

The negative obtained by the normal processes does not always possess exactly the desired qualities. Its contrast may not be sufficient, in which case it is necessary to *intensify* it. Its density may be too great and it may then be advantageous to submit it to the process of *reduction*.¹

Local defects in the negative or in the subject, or in the distribution of lights and shadows in the subject, may call for *spotting*, *retouching*, or *working-up*. Finally, it may be necessary to separate the gelatine film containing the image from its support, especially from the glass on which it was coated, with the object of reversing the image laterally; this process is known as *stripping*.

¹ Here and elsewhere throughout the text the established English words *reducer* and *reduction* are used for the French *affaiblisseur* and *affaiblissement* respectively, that is to say in respect to reduction in the photographic sense. It is hardly necessary to point out that, chemically, the reduction of a silver image is an oxidizing process.—Ed.

CHAPTER XVI

PREPARATION AND PROPERTIES OF NEGATIVES: GELATINE-BROMIDE EMULSIONS

191. General remarks on the Preparation of Emulsions. The photographic emulsion is not an emulsion in the normal sense of the word, but a suspension of microscopic crystals of yellowish silver bromide in gelatine. The dimensions and sensitivities of the individual crystals differ widely.

The gelatine itself has been recognized to be of considerable importance for the sensitivity of emulsions. Gelatine is extracted from bones or skin clippings of cows or pigs and varies considerably from batch to batch. These variations can only be smoothed out by blending a large number of batches. The gelatine molecule contains on an average some 15 amino acid groups joined together. Gelatine is insoluble in cold water, which, however, hydrolyzes the molecules, so that, at room temperature, 20 g of gelatine give up 0.05 g of hydrolyzed gelatine to one litre of water. (S. C. Goddard, 1942). This solubility explains why mildew is often formed on used photographic solutions.

It has been known for a long time that gelatines from different sources (or even different lots from the same source) possess marked differences in their photographic properties. Some of them give much more rapid emulsions than others, although these differences can only be shown up by actual practical photographic tests. Following from an observation by R. F. Punnett in 1924, S. E. Sheppard has found that these differences are due to the presence in varying proportions (from 1/200,000 to 1/1,000,000) of sensitizers, amongst them being thiosinamine (allylthiourea) and mustard oil (allyliso thiocyanate).

According to Steigmann (1928), sodium hyposulphite, which is formed from cystine during the process of lining of the gelatine, can also play the part of a sensitizer.

Emulsions are usually prepared by pouring a neutral or ammoniacal solution of silver nitrate into a slightly warm solution of gelatine containing potassium bromide with a small proportion of iodide. The mixing should be done during constant agitation, e.g. in a mixer, thus avoiding the possibility of any local excess of silver nitrate. The conditions under which the

mixing takes place, influence considerably the final characteristics of the emulsion. Slow, fine-grained emulsions are prepared from dilute solutions of salts, mixed in the presence of a large proportion of gelatine. Coarse-grain crystalline rapid emulsions are prepared from concentrated solutions of silver nitrate and potassium bromide mixed (all at a time or in several separate additions) in the presence of a small proportion of gelatine, the silver nitrate solution being introduced slowly, say over the course of 30 minutes, at constant temperature. Silver bromide-gelatine emulsions prepared without iodide have a white to pale yellow colour, whilst those containing a certain proportion of iodide are light greenish yellow. Both colours, however, change rapidly in light.

The emulsion thus prepared is then subjected to the process of *ripening*, which consists in heating it for a certain time at an accurately controlled temperature, in the presence of a silver halide, such as a surplus of bromide ions, or ammonia. During this process, which is often described as Ostwald ripening, the average size of the grains increases, the larger grains growing at the expense of the smaller ones. A sufficient quantity of a concentrated solution of gelatine is then added, so that after setting, the emulsion becomes a fairly stiff jelly.

After setting, the emulsion is shredded into noodles of about $\frac{1}{8}$ in. in diameter. Whilst in this form the emulsion is subjected to long *washing* in cold water until the excess of bromide and nitrates formed during the reaction, or any ammonia, are completely removed. The washed shreds are then kept in a cold store until they are used.

After draining, the shreds of the emulsion are melted in a water bath and the emulsion submitted to a second ripening often called *after-ripening* or digestion during which the speed increases often to a considerable extent. In the absence of silver halide solvents, no grain growth occurs. Chemical reactions take place between the gelatine and the sulphur sensitizers to produce traces of silver and silver sulphide on the grain surfaces. These traces constitute the *sensitivity specks* (§ 198). Sensitizer excess, or prolonged heat treatment at too high a

temperature, gives rise to *chemical fog*, a proportion of the grains becoming spontaneously developable. Incomplete digestion produces an emulsion whose sensitivity increases gradually on keeping. Different substances (doctors) are then added to the liquid emulsion, in particular chrome alum, which raises the melting point of the gelatine after it has been coated and dried; traces of potassium bromide (about 1 part to 100 parts of silver halide), which gives a cleaner image; certain dyes for colour sensitizing (§ 218), and, lastly, wetting agents (saponin, etc.), which lower the surface tension of the emulsion, and thus facilitate coating. In this form the emulsion is coated mechanically on any given support, previously given a *substratum* which varies with the nature of the support and which is used to ensure that the emulsion adheres to the support during the various photographic manipulations.

Paper emulsions are, as a rule, prepared by a different procedure, since they are neither washed nor subjected to an after-ripening treatment. The acidity or alkalinity of the medium at any one stage in the preparation of the emulsion influences considerably the photographic properties of the coated layers.

192. In spite of the considerable progress that has been made in the application of the methods of physical chemistry to the scientific control of the different phases of the manufacturing process, the preparation of photographic emulsions is still largely an empirical art. This is not likely to change until the intimate causes of sensitivity and the exact nature of the latent image are known, and as long as the manufacture of gelatine, a material of vital importance in the making of photographic emulsions, does not itself make the considerable progress which at present it shows no sign of doing. The position will improve if and when the gelatine can be replaced by a substance which is chemically less ill-defined.

193. The art of the emulsion maker lies in precipitating the silver salts in the form of grains having the desired photographic qualities, with a certain regularity and uniformity, in commercial quantities and over long periods.

Whilst it is relatively easy to obtain the necessary metallic salts with the desired degree of purity (total absence of copper, iron, and lead salts, the causes of desensitization and fog), the scientific testing of gelatine for photographic emulsions still leaves much to be desired, and is always supplemented by an actual manufac-

turing test on a semi-works scale. The properties of gelatine, even of the best-known brands, vary considerably from one batch to another, and especially from one season to another. These variations can be compensated for only by blending. Gelatines always contain different amounts of substances, formed by their degradation, of which some, soluble in cold water, are eliminated by washing, while others, which are insoluble, are sometimes useful and sometimes harmful in altering characteristics of the emulsion.

194. In photographic factories most elaborate precautions are taken in order to maintain constant the conditions under which the manufacturing processes are carried out, and to avoid all external causes of contamination.

A photographic manufacturing plant generally forms an enclosed space, and is connected with the outside only by self-sealing doorways for the passage in and out of the staff and materials. The air used for ventilation and drying is filtered free from dust and brought to constant temperature and relative humidity generally by washing it in chilled brine, which frees the air from dust and excess humidity, and then by passing it over heaters.

The precautions taken to ensure cleanliness and asepsis are at least as thorough as in the best surgical operating theatres. The staff may enter the part where the emulsions are made only when wearing special overalls and head-gear.

Rigorous chemical control is kept of the various raw materials as well as of the emulsion itself during manufacture and afterwards. Lastly, before the final coating takes place, a test coating is carried out to ascertain the photographic qualities of the emulsion. The silver is recovered from any unsatisfactory batch of emulsion. All those coated and issued under a maker's trade-mark may be regarded as emulsions of perfect quality, with their different characteristics lying between well-defined limits.

195. *The Sensitive Emulsion.* Emulsions vary widely in their characteristics, according to the maker and the purpose for which they are used. A typical emulsion for negative ciné work has given the following figures (1924)—

Emulsion (dried in air) per square foot;
42 to 70 gr—

Percentage Proportions of the Constituents

Water	10
Gelatine	55
Silver chloride	(traces)
Silver bromide	33 to 32
Silver iodide	2 to 3

Gelatine is considered to be "dry" when it does not contain more than about 15 per cent of moisture; in this state it is very flexible, but it becomes very brittle when the water content drops to 10 per cent.

A negative emulsion generally shows a very feebly alkaline reaction. Its melting temperature when swollen in warm water is about 95° F. (35° C.) in the case of fairly new plates and films, and increases slightly with age.

196. Microscopic examination of suitably diluted emulsions (Fig. 16.1) shows that the grains of silver halide in an emulsion have very

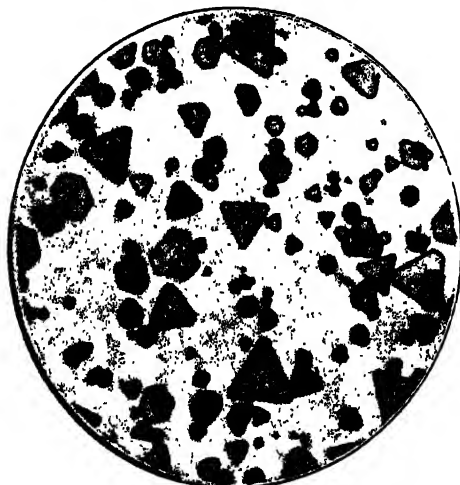


FIG. 16.1. PHOTO-MICROGRAPH OF THE GRAINS
OF A DILUTED FAST NEGATIVE EMULSION
× 4,000
(S. E. Sheppard)

different shapes and sizes. Under sufficiently large magnification the grains can be clearly seen to be crystalline and the forms identified with those derived from the "cubic" system. In emulsions prepared under neutral conditions (ripened with excess bromide), the grains are triangular or hexagonal tablets of thicknesses between $1/5$ and $1/15$ of their diameter. The large flat faces arrange themselves, during drying, parallel to the free surface of the gelatine. In emulsions prepared with ammonia, the grains are largely cubic in shape, with rounded corners and edges. Microscopic examination in polarized light shows double refraction, indicating the existence of internal strains which extend to the gelatine surrounding the grains.

In any one emulsion, the grains have very

different sizes, even in cases where the emulsion is not made by mixing two emulsions prepared separately. As a general rule the variation of the grain sizes is greater in sensitive than slow emulsions. In a single emulsion the large grains are always more sensitive than the small ones and contain a larger proportion of iodide. In an ultra-rapid emulsion having about 500,000,000 grains per square centimetre, with diameters lying between 0.2 and 3.9 thousandths of a millimetre, the distribution between the various sizes has been found as follows—

Less than 0.001 mm	61 per cent
From 0.001 to 0.002 mm	32 per cent
From 0.002 to 0.003 mm	6 per cent
Beyond 0.003 mm	1 per cent

The areas of the largest grains are about 200 times those of the smallest. In a slow emulsion for reproduction purposes, having about 3,000,000,000 grains per square centimetre, the ratio of the extreme areas was not more than 1 to 10.

The different properties of the grains of a single emulsion can readily be demonstrated by exposing a piece of plate or sensitive film to a very bright light; a microscopic examination of the film then shows that the different grains become coloured at very different rates.

If all the grains of an emulsion had the same sensitivity, it would be impossible to register with such an emulsion any values intermediate between black and white, since, in each region of the film affected by the light, all the grains would become developable at the same moment.

In emulsions which differ from one another merely in the duration of precipitation, sensitivity is proportional to the mean projected area of the grains. This simple relation does not hold if the emulsions are prepared under different conditions, especially with different gelatines. Thus it is a simple matter to make a slow coarse-grain emulsion. On the other hand we have learned in recent years how to prepare, specially for sub-standard cinematography, emulsions which are at the same time more sensitive and of finer grain than those used for photography with larger negative sizes.

After the grains have been reduced to the metallic state by development, they are roughly similar in shape to the original emulsion grains. As a rule the developed grains are somewhat enlarged, more or less regularly, the enlargement being greater the more energetic the developer used.

The free surface of the dried image, seen by

reflection, appears the shinier the fewer and smaller the silver grains. The clear portions of an image in a slow emulsion, clearer than those of an image in a rapid emulsion, are always more shiny. Superficial reduction, dissolving the grains nearest the free surface, leaves a uniformly shiny surface.

When a sensitive layer is exposed, a fraction of the incident light is scattered and reflected, another passes through the layer, a third is absorbed within it. It is only this third fraction, which is absorbed by the silver halide grains and which is photographically active. The distribution of light between the three fractions varies considerably as between different types of emulsions. By way of an example, we reproduce below some of the measurements by J. Eggert and W. Noddack (1923) on two types of silver bromide-gelatine plates which were not dye-sensitized.

Wave-length in μ	SENSITIVE EMULSION Percentage			PROCESS EMULSION Percentage		
	Ref'd	Abs'd	Trans'd	Ref'd	Abs'd	Trans'd
365	8	90	2	12	84	4
405	18	76	6	23	69	8
490	51	26	23	60	20	20
615	55	15	30	59	12	29

197. The Latent Image. With pure dry crystals of silver bromide, Hartung (1922) has demonstrated that the visible blackening (printing out) produced by light is caused by metallic silver, and that bromide is released at the same time. It seems but logical to assume that the latent image also consists of silver, but in amounts much smaller than those which constitute the visible print-out image.

One of the earlier hypotheses has been that both the latent and the print-out image are formed by an intermediary product, the sub-bromide of silver (Ag_2Br). Numerous attempts to demonstrate its existence, however, have never produced anything but a mixture in variable proportions of silver bromide and silver in a highly disperse state (colloidal silver) attached to the silver halide (Carey Lea, 1887).

H. Hilsch and R. W. Pohl (1931) have carried out important experiments on the liberation of various metals from their halides by means of different kinds of radiation. Thus they have exposed thick silver bromide crystals to radiation which was sufficiently penetrating to affect the whole depth of the crystal (X-rays),

the exposure time being so chosen that the energy absorbed was similar to that which produces a latent image in a photographic emulsion layer. In the crystal, the silver caused an intense violet coloration. If silver were released in the same concentration in an emulsion layer, and spread out in a continuous layer, it would be no more than two ten thousand millionths of a millimetre thick. It is clear, therefore, that so small an amount must remain invisible.

On the other hand analytical methods based on the study of X-ray diffraction diagrams have revealed that metallic silver is present in a pile of sensitive emulsion layers exposed to light but not showing any visible discoloration.

Numerous other experiments confirm the hypothesis that the latent image consists of metallic silver. One of the most convincing pieces of evidence is an old experiment by Luther (1890). Silver bromide or chloride-gelatine plates are exposed so as to produce either a latent image or a print-out image. The plates are then cut into strips and treated in pairs in oxidizing baths of various strengths. One finds that from a certain strength upwards, the latent image and the print-out image are destroyed simultaneously, whereas neither are weakened or destroyed in a weaker bath.

The destruction of a latent image by a bleaching bath only refers to the silver situated on the grain surfaces. Latent image can be shown to exist inside the grains, where it escapes the action of a bleaching bath and where it can be revealed by a developer containing a silver halide solvent, by development following treatment in a silver halide solvent (A. Kempf, 1937) or by breaking up the grains by treating the emulsion with iodide ions. These transform the silver bromide crystals into a polycrystalline mass of silver iodide so that the developer can reach the internal image (Lüppo-Cramer, 1924). Meidinger (1937) has managed to determine the amounts of superficial and internal image by very delicate micro-analytical methods. Internal silver in appreciable quantities was found only for very intense illumination or at very low temperatures.

By iodizing the silver bromide in a photographic plate (F. F. Renwick, 1920), it is possible to develop photographic plates in bright light. This procedure is not of any practical importance, but, like the possibility of developing a latent image physically after fixation, it demonstrates again the substantial nature of the latent image.

198. It has been shown by J. Dewar (1894) that a latent image can be formed at temperatures as low as that of liquid air (-186°C), when chemical reactions are completely arrested. The sensitivity of an ordinary emulsion exposed to white light at -250°C is approximately 1/25 of that at 20°C (W. F. Berg and K. Mendelssohn, 1938). This loss in sensitivity is explained by the fluorescence which W. Meidinger (1939) has discovered to occur at low temperatures.

The explanation of the mechanism of latent image formation at low temperatures is based on an ingenious hypothesis (A. Dauvilliers, 1920, and K. Fajans, 1921) which has been confirmed by more recent publications (N. F. Mott and R. W. Gurney, W. F. Berg and K. Mendelssohn, J. H. Webb and C. H. Evans, 1938). These workers consider the liberation of metallic silver as a secondary process, which at room temperature occurs simultaneously with the primary process, but which for exposures at low temperatures does not take place until the emulsion is warmed.

The primary process is entirely physical in nature, consisting in the liberation of an electron from a bromide ion in the crystal lattice by the action of light.¹ These electrons move about freely in the crystal, until they are trapped by irregularities in the crystal, in particular by the *sensitivity or concentration specks* formed during after-ripening (§ 191). At room temperature, the negatively charged sensitivity speck is discharged by a neighbouring silver ion which thus reverts to the atomic (metallic) state and which sticks to and enlarges the speck. At low temperatures, the electrons merely charge up the sensitivity specks, each of which cannot hold more than a single electron, the charge of which is sufficient to repel any other electrons (W. F. Berg, 1943).

As a result of exposure, bromine is liberated in the silver halide crystals, through which it can be shown to move freely (O. Stasiw and T. Teltow, 1941-1944). On reaching the surface of the crystal, it will react with the gelatine, thus avoiding the recombination between silver and bromine. Gelatine, however, is not a very efficient bromine acceptor. This accounts for the weakening and eventual destruction of the

surface image by bromine liberated from the interior of the grain. An efficient halogen acceptor must be added to an emulsion if appreciable quantities of silver are to be formed, as for example in paper print-out emulsions.

199. The concept of the sensitivity centre has been first suggested by A. Abegg (1897) and has been refined by S. E. Sheppard, A. P. H. Trivelli, and R. P. Loveland (1925). F. Weigert (1928) has demonstrated that free silver is present in ripened emulsions. Treatment of an after-ripened emulsion with oxidizing agents causes the sensitivity to be reduced to that before after-ripening began.

Various results lead one to assume that a photographic grain becomes developable if the total number of silver atoms on a sensitivity speck exceeds a minimum critical number, estimated to be of the order of 5. This is the reason why the grains become spontaneously developable if after-ripening is pushed too far. If there are no sensitivity specks, the silver atoms are formed at several points in and on the crystals and the various specks so formed compete with one another for any further silver atoms formed. Thus one can see why the exposure necessary to cause a grain to become developable is smaller the smaller the number of sensitivity specks, and the nearer the number of silver atoms in the specks is to that necessary to induce development.

Microscopic observations on diluted emulsions show that under intense illumination the blackening begins at a few isolated points on each grain. These points are probably the sensitivity centres, and it is likely that it is on one of these points that development also commences. The photomicrographs (Fig. 16.2) show grains before development and the development centres after brief development and fixation, and finally, by combining the two pictures, the position of the centres on the grains (T. Svedberg, 1922).

200. **Different Actions on the Photographic Emulsion.** The photographic emulsion is sensitive not only to ordinary visible light but to other kinds of radiations such as the infra-red, the ultra-violet, X-rays and similar radiations emitted by various radio-active bodies, nuclear particles such as α -particles, protons, and electrons and even in certain conditions by supersonic waves. We may note here that with X-rays, gamma rays, and nuclear particles, the presence of sensitivity specks is not so important as it is with light, since some of these agencies at least produce considerably more

¹ An electron is the smallest possible unit of charge of negative electricity. In crystals or in solutions of salts, the metal and the acid radicals are not in the molecular or the atomic state, but in the *ionic*. This means that they are not electrically neutral, but carry one or several charges of electricity, positive for the metallic ions (cations) and negative for the acid ions (anions).

silver in each grain than is necessary for development. Images can also be obtained by static electric discharge in contact with the film.

Different mechanical actions, such as sliding pressure¹ (friction of a blunt point), rubbing, etc., all cause the emulsion to become developable (*abrasion* of the film), and at the same time make the emulsion insensitive to the subsequent action of light (O. Bloch, 1915). These effects show up more strongly when followed by an exposure to light. Thus an abrasion can give rise to black marks in the whites of an image and white marks in the black.

Contact with the emulsion of a great number of reducing solutions (sodium arsenite, stannous chloride, etc.), or of gaseous reducers (hydrogen sulphide, hydrogen phosphide) causes fog, which varies with the strength of the agent and the duration of the treatment.

Special mention must be made of the action of hydrogen peroxide,² first noticed by W. J. Russell in 1899, and more recently studied by Lüppe-Cramer (1915), S. E. Sheppard and E. P. Wightman (1923), W. Clark (1923), M. W. Jones and J. M. Blair (1937), and others. Certain other oxidizing agents have similar effects.

The contact of a fully ripened emulsion layer with neutral or acid solutions of hydrogen peroxide or with the vapours evolved by these solutions, causes a series of phenomena which are all analogous to those arising from the action of light (such as formation of a developable image, reversal, and solarization). Ozonized air has similar characteristics. In alkaline solution hydrogen peroxide is a developer of the latent image, and does not give rise to fog.

A very large number of organic substances, and some metals, oxidize slowly in moist air and give rise to traces of hydrogen peroxide (or ozone), which can act on sensitive emulsions from a distance and cause fog. This applies, for example, to different kinds of wood (especially resinous wood), turpentine, and other vegetable essences, numerous resins, base resin varnishes, lignites, and, amongst metals, zinc, and, to a less degree, aluminium and magnesium.

¹ Pressure applied without friction to a sensitive emulsion during exposure usually produces a desensitization of the emulsion, the normal rapidity reappearing as soon as the pressure is discontinued (E. Poindexter, 1931; Ny Tst-Zé, 1932).

² Although hydrogen peroxide may be in general a powerful oxidizing agent, it is known that it can cause the reduction of different bodies (ozone, permanganate, silver oxide) whilst being itself reduced, its oxidizing or reducing power depending on pH.

This phenomenon is sometimes referred to as the *Russell effect*.

Several of the substances mentioned are normally used in cameras and plate holders. This explains the fog which is often found on a plate which has been left in its holder for a long time, especially in one of recent construction. These effects cease as soon as the surface oxidation is completed. Other metals, which are non-oxidizable, act at a slight distance on

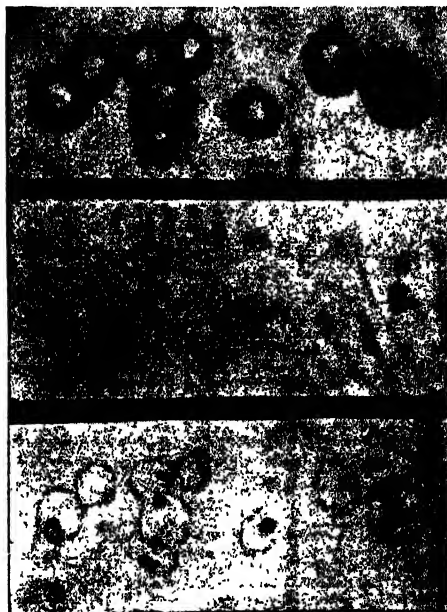


FIG. 16.2. DEVELOPMENT NUCLEI $\times 4000$
(T. Svedberg)

sensitive emulsions after a very long stay in darkness. This action has been attributed to a secondary radiation produced in the metal by cosmic radiation (J. Reboul, 1936).

A specially interesting case is that of the action of paper on the emulsion. Niépce de St. Victor (1857) attributed the action on a photographic plate of a piece of paper which had previously been exposed to the sun to an invisible radiation, comparable with phosphorescence. It is now known that this action is due to the formation of hydrogen peroxide by the oxidation of the size in moist air, and that it can be impeded by agents which destroy the hydrogen peroxide, or by protective coatings

which stop the free access of air, such as gelatine, rubber or cellulose varnishes. Similar complex phenomena may be noticed when a paper, having printed or written letters on it, is placed in contact with the film; according to its nature the ink may exert a more intense action than the paper, or conversely the metallic salts in the ink may desensitize the emulsion, so that, after a sufficiently long time in contact, the image of the text may appear, on development, dark on a clear background or light on a dark background.

These effects may be observed even if paper has been badly charred, a fact which has been employed, for example, in deciphering documents rescued from a fire (R. Davis, 1923).

201. The Density of a Photographic Deposit. The definition of optical density given earlier (§ 15), is not sufficient for media which scatter the light. Only for a non-scattering medium is the density value independent of the method of measurement, and this does not apply to the photographic density deposit, which scatters light strongly. When measuring the density of a developed plate, one finds, as a rule, as many different density values as corresponds to the types of densitometers used. Thus for example, the density values obtained photographically by printing on to another photographic material (*contact printing or diffuse density*) are considerably smaller than those produced by projection printing. This is particularly noticeable if the negative is illuminated by a condenser and if the transmitted flux is collected within a limited cone of acceptance only. This effect, first studied by Callier (1909), has been named the Callier effect.

A light sensitive system in contact with the plate to be measured registers all the light transmitted, whether the receptor is a photographic plate, a photo-electric cell, or the photometric apparatus known as an integrating sphere. This consists of a hollow sphere (W. E. Sumpner, 1893) of relatively large diameter, coated with a white reflecting paint, which receives the luminous flux to be measured through a small aperture. The brightness of the interior of the sphere is measured through another small hole at right angles to the first and is proportional to the total flux entering the sphere. Under these conditions, the value for the opacity, and thus the density, is smallest. Conversely, a receptor placed at a relatively long distance from the negative (the projection lens, for the case just considered, or the majority of visual photometric apparatus) measures but a fraction

of the light flux passing through the negative, a fraction which is smaller, the narrower the solid angle formed between the point being measured and the outline of the receptor. Under these conditions, the value for opacity, and thus for density, will be very high.

When the negative is illuminated by completely diffuse light, so that any one point receives light from all possible directions, a density value close to that obtained by contact printing will be measured. The light which without the negative would have reached the receptor, and that which originally would have missed the receptor and is scattered on to it by the negative, compensate one another fairly accurately. This is why a plate to be measured is as a rule placed against an opal glass, if contact printing density is to be measured. If the negative is used for projection printing, as in an enlarger, or if the density of a positive is to be measured, as for cinematography, readings are significant only if determined under conditions sufficiently similar to those for which they are to be used. There is not, in fact, a single value of *spectral density*, but as many different values as there are measuring instruments.

In all those instances where the image is not a perfectly neutral grey, discrepancies will be found between visual densities, and those determined by physical receptors such as photo-electric cells. More meaningful results will be obtained, if the spectral sensitivity of the eye or of the measuring device is corrected by means of a suitable filter so as to become similar to the printing material to be used.

Because of the discontinuous nature of the photographic deposit, the ratio of the mass of the reduced silver (in grammes per decimetre square) to the diffuse density known as the *photometric constant* is not a constant number. Hurter and Driffield assumed it to be constant and of the order of 0.01; more accurate measurements by S. E. Sheppard and C. E. K. Mees (1907) have shown that the ratio, which they called the photometric equivalent, varies with the emulsion, the development, and the intensity of the exposure. J. Eggert and A. Küster (1937) have demonstrated that a linear relationship exists between the photometric equivalent P and the average diameter d of the grain (over a range from 0.4 to 1.6 μ). The relation is $P = 0.0184 d + 0.0033$ and does not depend on the emulsion or the value of the density.

202. Characteristic Curves. It is not at all

easy to compare the properties of two sensitive materials merely by the inspection of two negatives, even if these are taken under otherwise identical conditions. Even if the brightness distribution in the scene taken were known exactly, the effect of the lens and of any irregularities in the behaviour of the shutter would mean that the intensity and thus the exposure for any part of the negative is unknown. Finally, even if the exposures were known at all points, as might be the case in contact printing, they are distributed at random, and a comparison of the two plates could be carried out only by holding them side by side.

By printing through a *sensitometric tablet* or *step wedge* with known density steps arranged in a regular order or with a continuously increasing density and appropriate markings, one can apply to a photographic material a series of exactly specified intensities and exposures. The exposure scale can be made much longer than that available from a single negative, thus covering all the exposure values that would be obtained, if a scene were photographed with a wide range of exposure times. The results obtained on different materials are easy to compare if the two density scales are laid side by side with the parts which have received the same exposure next to one another. Under these conditions, pictorial considerations will not interfere with the technical aspects.

Continuous sensitometric density wedges are produced by grinding and polishing a slip of glass containing a black, light-absorbing material into the form of a prism with a very acute angle, cemented to a similar prism of clear glass, so as to ensure that the faces are parallel. Less accurate wedges are obtained by casting gelatine containing drawing ink, or graphite, or reduced silver, or a mixture of dyestuffs (Goldberg, 1910). If we consider equidistant points along the wedge, the thicknesses of the absorbing layers, and with these the densities, are in an arithmetical progression. The wedge is then completely described if one knows the density at one point and the wedge constant, which indicates the density difference between any two points being 1 cm apart along the wedge. Cast wedges always display local irregularities, which may be neglected, however, unless measurements of high precision are required. The density value for a cast wedge containing scattering particles will depend upon the methods

of measurement (§ 201). The density values commonly stated are those of contact printing density. Density wedges are not always perfectly neutral, i.e. both the density at any one point and the wedge constant may depend upon the colour of the measuring light and on the spectral sensitivity of the material being

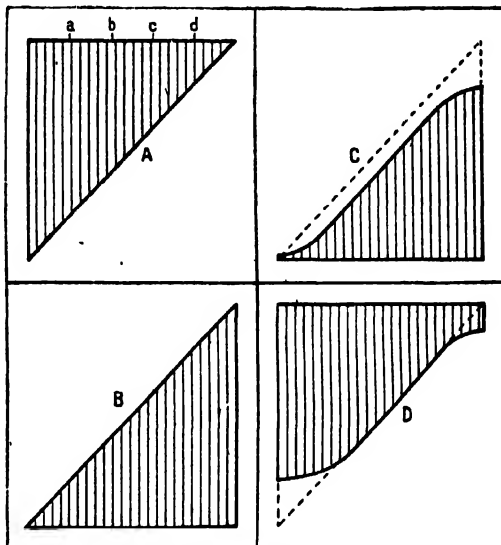


FIG. 16.3. DIAGRAMMATIC REPRESENTATION OF THE CHARACTERISTIC CURVE

exposed. We shall consider below how a wedge can be calibrated under the conditions of use.

203. Let us consider the result of printing a perfect optically neutral density wedge on to a plate or film. A section through and along the wedge is indicated in figure 16.3A on a much exaggerated scale.

If the negative obtained were perfect, so that the silver was distributed as shown, on a convenient scale, in Fig. 16.3B, then the "wedge" and the negative, if superposed, would make a uniform density. We should then be able to obtain from that negative by a second print made under the same conditions, a perfect *facsimile* of the original wedge.

Actually, however, it is known that whatever kind of sensitive film be used for one or other of the prints, the ideal result is never attained. Under the most favourable conditions the distribution of reduced silver in the negative may be like that shown in Fig. 16.3C. Another copy made under identical conditions will not give a

facsimile of the original screen but a distorted scale of tones indicated in Fig. 16.3D.

Since the densities of a processed photographic layer are in practice proportional to the mass of reduced silver per unit area, the curves C and D represent also the densities of the negative and the positive plotted against the logarithm of the transparencies of the original wedge. By multiplying the abscissae by the

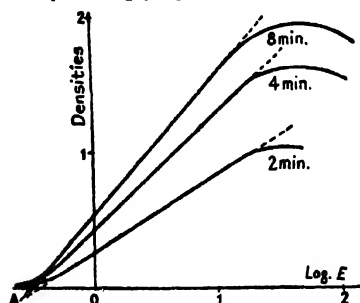


FIG. 16.4. CHARACTERISTIC CURVES OF A PLATE FOR DIFFERENT TIMES OF DEVELOPMENT

appropriate factor, taking care of the illumination and the exposure time used, the densities would be plotted against the logarithm of the exposure. A curve such as C is called the *characteristic curve* of the sensitive material which was used to make the negative. A curve such as D might be called a reproduction curve, into which enters both the properties of the negative and the positive materials, as well as the intensity and time of exposure and the conditions of development of both processes.

204. F. Hurter and V. C. Driffield (1890) made the happy choice of logarithmic scales both for the opacities and the exposures and were thus able to represent in the most useful manner the photographic effect of exposure and development under fixed conditions. The *characteristic curve* which is a plot of the densities obtained against the logarithm of the exposure in metre-candle seconds may be described in general terms as follows. There is as a rule a more or less extended straight-line portion, the slope of which is called the contrast factor or more usually, the *gamma* (γ), which is of great practical importance. The gamma is measured as the tangent of the angle which the straight-line portion of the curve makes with the exposure axis. As development proceeds, the slope increases continuously, at first rapidly, then more and more slowly, until a limiting

value is reached which is described as the *maximum gamma* or *gamma infinity* (γ_{∞}). The value of γ_{∞} depends on the sensitive material, the developer, and sometimes also on the average light intensity received by the layer. In Fig. 16.4 are shown three characteristic curves obtained on the same material and developed in the same developer at constant temperature for three different times. Some workers reserve the term characteristic curves to those for which γ is 1 (slope of 45°), but this condition cannot always be satisfied, in particular with modern fast emulsions of the "portrait" type, which have a maximum γ of the order of 0.8.

In order to provide a more complete description of the behaviour of a photographic material one often plots the gamma and the fog against the time of development. In Fig. 16.5, the gamma values are shown on the left and the fog values on the right, plotted against the time of development in minutes, the gamma curve being shown smooth, the fog curve dotted. Curves are plotted for a fine grain (A) and a high-contrast (B) developer used with the same photographic material.

In Fig. 16.4 it will be seen that the extensions

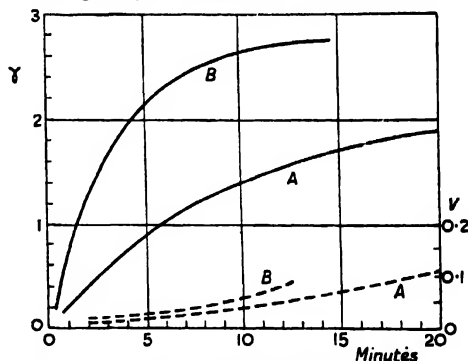


FIG. 16.5. THE CHANGE OF GAMMA (CONTINUOUS LINE) AND FOG (DOTTED LINE) PLOTTED AGAINST TIME OF DEVELOPMENT FOR ONE MATERIAL AND TWO KINDS OF DEVELOPER, A AND B

of the straight-line portions of the characteristic curves for different times of development meet in a point A below the abscissa. It is often found that curves meet in one point in this fashion, but sometimes the point is situated on and occasionally even above the axis. If the same material is developed in solutions made up with increasing amounts of bromide ions, the

meeting point is found to rise vertically with increasing bromide concentration.

Plates or films are often double-coated with two different emulsions or coated with an emulsion blended from several different component emulsions. The characteristic curves of such materials are often less smooth than those shown in Fig. 16.4. Curves often display a kink, consisting of two straight-line portions with a more or less extended transition section. The curve shape shown in Fig. 16.4 is often found with slow emulsions, such as process materials or lantern plates. The characteristic curves for fast emulsions show as a rule a long curved portion, often called the toe, followed by a relatively short straight-line portion. In the course of experiments carried out on a large number of emulsions prepared by various methods, L. Silberstein and A. P. H. Trivelli (1942-5) have found that the characteristic curve for a pure bromide emulsion is symmetrical around its point of inflexion (centre of straight-line portion) if the emulsion is prepared without sulphur sensitizers. The curves for emulsions which have been after-ripened in the presence of sulphur sensitizers are not symmetrical. These curves may be considered as consisting of two often symmetrical components, which themselves depend upon the sensitivity of the individual grains and thus allow the specific effect of after-ripening on the grains to be determined.

205. Identical exposures can be obtained with widely different values of the individual factors, intensity, and time. Let us consider first the characteristic curves obtained by means of a sensitometric tablet, by varying the exposure time over a wide range. For astronomical work, the time of exposure may run into many hours; in popular photography, the majority of photographs is taken with a time of around $1/25$ second; in sound recording for cinematography, exposure times may be less than $1/25,000$ second. The characteristic curves obtained under these conditions differ from one another even for the same photographic material and constant development conditions, and in particular gamma values vary considerably. For very short times of exposure, gamma is often considerably lower than for normal or long times of exposure, and development may have to be prolonged, often by as much as 50 per cent, in order to obtain the normal gamma value, when processing, say, a negative exposed by an electronic speed lamp.

On the other hand, the shape of curves obtained for constant intensity and varying times of exposure (time-scale curves) depends upon the value of the intensity of light. The time-scale gamma is often very low for low intensities of light and increases with the intensity. Time-scale curves were obtained by the sensitometric procedures originally suggested by Hurter and Driffield, and by Scheiner, and are still used occasionally because of the ease with which a time scale of exposures can be produced in the laboratory.

A sensitometric investigation has no practical significance unless the exposure time is near to that used in practice. Characteristic curves should never be published without a statement on the exposure time used.

Let us point out here that there are always slight differences between the characteristic curves of different batches even of nominally the same emulsions. Thus sensitometric data strictly apply only to the batch tested, and not to other batches of the same type of emulsion, or even to the same batch after a lapse of some time.

206. It is useful to describe in more detail the shape of the characteristic curve. On increasing the exposure, we find that the density rises gradually from a low constant density present even without exposure and designated as fog or veil. This lower curved part of the curve is often loosely described as the region of *under-exposure*. The slope then rises rapidly until it reaches its maximum value (the gamma, γ) in the straight-line part of the curve, called the *normal exposure region*. The length of this region measured on the exposure axis shortens as development is increased so as to obtain greater gamma values; it is followed by the *over-exposure* region or the shoulder of the curve in which the slope of the curve gradually diminishes and finally becomes zero (curve parallel to the exposure axis). The maximum density plateau thus reached is followed by a descending branch of the curve known as the region of *reversal* or *solarization*. When exposure is increased considerably, it is sometimes found that the curve will rise again, a phenomenon described as the *re-reversal* of solarization. It is said that some materials exhibit several cycles of reversal and re-reversal with diminishing amplitude.

It will be seen that a certain tone difference in the subject is reproduced by a pair of densities in the negative which at first increases with increasing exposure (region of under-exposure), then reaches a maximum value (region of normal

exposure), to decrease again and to become zero (region of over-exposure), and finally, to reverse its sign (solarization region). Thus for a sufficiently prolonged exposure, the scene is reproduced as a positive, perhaps only in its brightest portions, but sometimes completely. The quality of reproduction obtained on

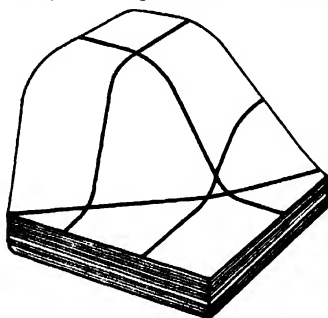


FIG. 16.6A. PERSPECTIVE VIEW OF A DENSITY SURFACE FOR A LANTERN PLATE

The scale for the upright density axis is 2.5 times that for the intensity and time axes (H. Arens and J. Eggert)

ordinary materials in this way is, however, not as a rule satisfactory.

The exposure region between the two points at which the slope of the curve is $1/3$ of the maximum (gamma) value is in French literature called the "interval of differentiated exposures" of the emulsion in question. The underlying assumption is that tone differences in the scene falling outside this region will not be reproduced satisfactorily in the print. This region, sometimes, and inappropriately, called the exposure latitude is better described as *exposure range*.

207. Density Surfaces. A single characteristic curve, or even a set of curves obtained for different times of development, is not sufficient to describe completely the properties of a photographic layer (§ 205). In order to describe completely the blackening law for a photographic material, a three-dimensional representation is necessary. For the so-called density surface, the logarithm of the intensity is plotted along one dimension, the logarithm of the time along the second, and the density obtained for any one intensity and time is plotted upwards. The concept of the density surface was put forward by G. R. Harrison and E. Hesthal (1924); actual typical surfaces have been prepared and published by H. Arens and J. Eggert (1928-35).

Fig. 16.6A shows a perspective view and a plan of a density surface for a lantern plate.

The curves in Fig. 16.6B are lines of constant density ranging from 0.05 to 4.5. On examining the perspective view one can see at once that the time-scale characteristic curves differ in shape from the intensity scale curves. The time-scale curves are the intersections of the density surface with a vertical plane containing the time axis, the intensity-scale curves one containing the intensity axis. It is also seen that the maximum density obtainable with a time scale of exposures is much lower for an intensity level of 0.004 metre candles than for 2 metre candles. Curves for these two intensity levels are drawn on the perspective figures; the maximum density values are 3.0 and 4.5 respectively.

208. Summation Errors of Photographic Materials. A very important advantage of the photographic method is that a photographic material is capable of summing up a continued exposure to low-intensity light lasting for a long time. In this way it is possible to record radiation which is too feeble to be measured in any other way. It is said occasionally that a photographic plate is capable of integrating exposures. This

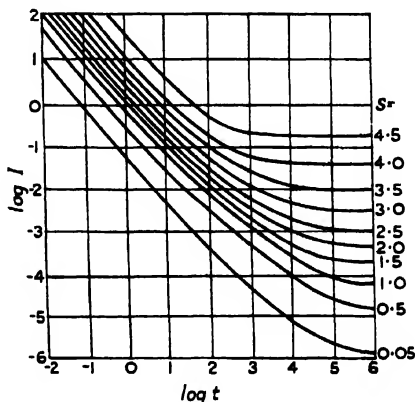


FIG. 16.6B. PLAN OF THE DENSITY SURFACE SHOWN IN FIG. 16.6A

Each curve represents a contour line for the density value shown on the right.

is not strictly correct, however, since the reciprocity relationship, formulated by Bunsen and Roscoe (1862) for certain photo-chemical reactions, does not apply to the photographic process. The reciprocity law states that equal exposures should produce equal photo-chemical effects, no matter what the individual values of intensity and time (§ 205).

The reciprocity law is valid, however, for direct exposure to X-rays. It also applies over a limited range of intensities at room temperature for exposures to light, so long as the exposure time is shorter than a certain limiting value, which for a series of emulsions was found to be of the order of 0.00004 second. This limiting exposure time increases with decreasing temperature (W. F. Berg, 1940) and for temperatures as low as that of liquid air or hydrogen extends over the whole range of intensities and times investigated and likely to be used in practice.

We should point out here that the density produced is not as a rule proportional to the total mass of silver in the latent image. The existence of solarization implies that the amount of silver and the density may even vary in the opposite sense.

For any photographic material, there is a limit of light intensity below which no photographic effect can be obtained. This critical intensity is lower the faster the emulsion in question, and also depends upon the method of preparation of the emulsion.

For intensities above this critical value, the maximum number of grains that can be made developable on prolonged exposure increases with increasing intensity. It is never possible to make all the grains in an emulsion developable, whatever the conditions of exposure, but a maximum possible number is affected for an intensity of light far in excess of the minimum value. L. A. Jones and V. C. Hall (1926) have found this optimum intensity value to be 0.08 meter-candle-seconds for a fast film, 5 for a slow negative material, and 316 for a slow lantern plate. In the region between the minimum threshold and the optimum intensity, both maximum density and gamma increase with the intensity.

K. Schwarzschild (1899) has formulated a law which is named after him and which he derived from a study of the photographic photometry of the magnitude of stars, i.e. to the case of extremely weak intensities. The law states that equal photographic effects will be obtained for a pair of intensities (I) and times (t) of exposure, if the relation $(\log I + p \log t) = \text{constant}$ is fulfilled. Here p is a constant known as the Schwarzschild constant, which he found to be 0.85 for the plates he used and an exposure time of several hours. Occasionally, this law has been unduly generalized and has been applied to the times and intensities used in

more normal photographic practice. It applies only over a small range of intensities at a time, the factor p varying continuously with the intensity and thus never actually being constant. Thus for a fast negative plate, H. Arens and J. Eggert (1928) obtained values of p which varied progressively from 1.85 to 0.4, as the exposure time was increased from 1/10,000 to 1,000,000 sec.

If, for a constant intensity and total time of exposure, the effect of a continuous exposure and of intermittent exposures is compared, it is found that the photographic effect is not identical. As a rule, the intermittent exposure is less effective than the continuous. The *intermittency effect* is closely linked both with the growth of the latent image and the deviations from the reciprocity law. This effect does not become obvious unless the frequency of interruption is below a critical value, which for any one emulsion is nearly proportional to the intensity, and which, as between different emulsions, increases with the sensitivity of the emulsion (J. H. Webb, 1933). According to this author the critical frequency of a rapid emulsion is of the order of 60 for a normal intensity level. With another fast emulsion, R. A. Sawyer and H. B. Vincent (1943) have found that the intermittency effect is still appreciable at 165 interruptions per second.

209. Various Photographic Effects. We review here very briefly several photographic effects, in all of which the sensitive material fails to integrate two kinds of radiation which are applied successively. These effects are named after their discoverers.

Becquerel Effect. A latent image on a Daguerrotype plate is intensified by illuminating it with green or yellow light to which the virgin plate is insensitive (E. Becquerel, 1841). Similar effects can be obtained on print-out papers, using green light. In silver bromide emulsions it does not occur, except in the special case of an X-ray exposure, followed by an exposure to light sufficiently heavy to cause printing out. The print-out silver is formed preferentially on the X-ray image (R. Luther and W. A. Ushkoff, 1903).

Herschel Effect. The latent image in an emulsion which is not normally sensitive to red or infra-red light, can be weakened or even wiped out by an exposure to this inactinic light, in particular if the emulsion contains an excess of soluble bromide (J. Herschel, 1839). The effect, originally described for a print-out

image, is more pronounced the higher the intensity at which the latent image to be bleached is produced (W. Leczynski 1926-7, and L. Falla, 1941-2); it does not depend on the intensity of the bleaching radiation, i.e. the reciprocity law is fulfilled. When an image has been bleached away, the emulsion behaves again like a virgin emulsion, although sometimes its sensitivity to actinic light is increased (L. Falla, 1941-2). The Herschel effect is more pronounced for pure silver bromide emulsions (certain bromide papers) than for iodo-bromide emulsions (fast negative emulsions). It is sensitized by desensitizers and the presence of copper salts and cannot be demonstrated in the presence of sensitizing dyes, i.e. in orthochromatic or panchromatic emulsions (A. P. H. Trivelli, 1929). The effect has found various practical applications.

Clayden Effect. Under certain favourable conditions, a latent image produced by an intense light flash of short duration (1/1000 sec or less) can be destroyed by a subsequent exposure to light. Thus it is possible to produce a direct positive image in a camera if the photographic material has been flashed uniformly previously (P. Villard, 1907). Even under less favourable conditions, the Clayden effect always manifests itself by a desensitization if a very short exposure is followed by a longer one. When the order of the two exposures is reversed, their effect is largely additive. A similar result is observed when the first exposure is of any duration to X-rays; the effect is then known as the *Villard Effect*.

Sabbatier Effect. An image can be changed from negative to positive if the material is uniformly flashed while in the developer (Sabbatier, 1850). This effect is often accompanied by a dark edge due to irradiation (§ 212) surrounding the clear portions of the plate. (G. W. W. Stevens and R. G. W. Norrish, 1938). These edge effects are occasionally utilized for the production of peculiar pictorial effects (§ 734).

Albert Effect. If after a very heavy exposure a photographic material is treated in a dilute solution of chromic acid, rinsed, and then uniformly exposed to light, it develops to a positive image of the first exposure. This effect is due to the fact that latent image forms both in the surface and in the interior of the grain. When the superficial latent image has been bleached away, further latent image will tend to form in the interior of those grains, which carry an internal latent image due to the first

exposure. A normal superficial image will be formed on those grains which have not received a sufficiently strong first exposure (G. W. W. Stevens, 1939).

210. Reversal by Solarization. When a series of increasing exposures, extending over a very wide range, are given to an emulsion, we have seen (§ 206) that after development the resulting density first increases, reaches a maximum, and then diminishes until it practically vanishes. In 1880 Janssen suggested the existence of a second range of increasing densities beyond the point where the blackening had decreased to nothing. Thus, in photographing a natural object, it is possible, according to the exposure given, to obtain either a normal negative, or an almost uniform high density (first neutral zone), or a more or less satisfactory positive (image reversed by solarization), or, lastly, an almost uniform and very weak density (second neutral zone). Generally speaking, the time of exposure necessary to obtain a direct positive on an ordinary emulsion is 1,000 times that necessary to give a satisfactory negative, but this process is uncertain and is used only with special emulsions.

Although the density obtained by chemical development passes through its various maxima and minima, the total amount of latent-image silver increases continuously. The distribution of the latent image between the surface and the interior of the grains, however, changes considerably, the superficial silver becoming oxidized back to silver bromide by the bromine which is released as the internal silver is being formed. (J. H. Webb and C. H. Evans, 1941). Emulsions containing iodide or a surplus of soluble bromide solarize easily, but solarization is impeded or at least reduced for emulsions with very fine grains or containing halogen acceptors which are more effective than the gelatine, such as sodium nitrite, hydrazine salts, or phenylene diamines. The grains of an image which has been reversed by solarization are finer than those in a normal image, because it is always the large grains which solarize first (W. Meidinger, 1937). Solarization can sometimes be made to disappear by treating the emulsion before development in an oxidizing bath (Lüppo-Cramer, 1905), which has the effect of favouring the internal latent image by reducing or destroying the surface image.

The reversal by solarization always disappears if development is prolonged sufficiently. Since solarization has been caused by the destruction

of the superficial latent image, it takes some considerable time for the developing solution to dissolve the silver halide grain sufficiently for the internal latent-image specks to be laid bare. In this way one can account for the fact that at least with certain physical developers, solarization does not occur, and that it disappears if a silver halide solvent is added to a chemical developer, or if the emulsion is treated with a silver halide solvent before chemical development (H. Arens, 1934).

211. Graininess. In enlargements considerably smaller than those necessary to be able to see the individual grains, such as in projections or enlargements of some 20 times linear, the image is seen to be non-uniform. This is due to the irregular arrangement of the photographic grains in the emulsion, which are superimposed one upon the other in the thickness of the coated layer. This visibly irregular structure is called the *graininess* of the image (Fig. 16.7) and is more apparent the larger the grains in the emulsion.

On the other hand, we must consider the *granularity* of a photographic deposit. This is a measure of the statistical variations in density of an apparently uniform silver deposit which is scanned by a narrow ray of light. Whereas the granularity, measured objectively, for example by a micro-photometer, grows continuously with increasing density, the graininess, which is determined subjectively, becomes less obvious as the visual acuity of the eye decreases; in other words, it tends to disappear for sufficiently high densities. On a negative the graininess reaches a maximum for a density of 0.3 at which there are equal areas absorbing and transmitting light.

The granularity of printing materials is much less than that of negative materials and its effect may be neglected when enlargements are considered. The print graininess G_A as determined on an enlargement is proportional to the granularity G_N of the negative, to the degree of enlargement A , and to the slope of g_P of the characteristic curve of the printing material. If the exposure of the negative is the shortest possible normal exposure, and the print the best one possible, the expression $G_A = AG_N g_P$ can be replaced by $G_A = AG_N / g_N$ in which g_N is the slope of the characteristic curve at a density where the granularity is G_N (E. W. H. Selwyn, 1943). It will be clear that for a perfect print the product of $g_N \cdot g_P$ should be unity. The expression G_N / g_N is proportional

to the graininess as appreciated visually and can therefore be regarded as an objective measure of the graininess. This graininess value reaches a maximum at that point on the negative characteristic curve where the exposure is ten times that required at the speed point according to the Jones criterion (point *A* in Fig. 18.3). The graininess of a sensitive material

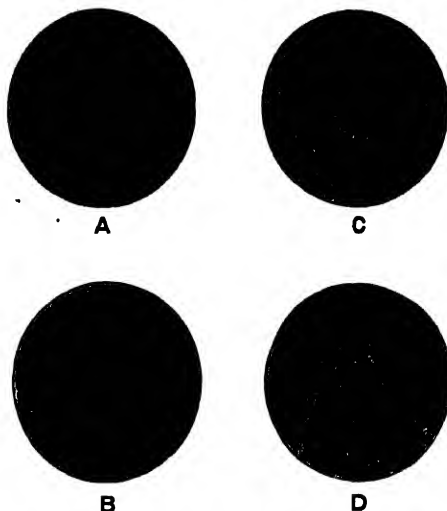


FIG. 16.7. GRAININESS OF A PHOTOGRAPHIC EMULSION FOR FOUR DIFFERENT MAGNIFICATIONS (C. E. K. Mees)

A = 20 diameters. C = 400 diameters.
B = 100 " D = 900 "

may therefore be represented by the maximum graininess value.

It is always important to maintain the graininess of negatives at as low a value as possible, in particular for miniature work in which prints are invariably enlargements. We shall deal below with methods of fine-grain development; here we need only note that with these it is always necessary to increase the exposure to a considerable extent.

212. Irradiation. During exposure each point of the photographic emulsion layer acts as a source of light towards the neighbouring parts of the layer. Thus a bright part of the image appears to spread at the expense of the neighbouring darker portions. This fact is known as *irradiation*; it is responsible for the fact that the image of a point or a slit spreads proportionally to the logarithm of the exposure

(J. Scheiner, 1897; C. Féry, 1898). The proportionality constant, which measures the increase of a star image in microns as the exposure is increased by a factor of ten, varies considerably from emulsion to emulsion. A few figures are given below, according to measurements by Goldberg (1913).

Positive Plate	Process Plate	Fast Negative Plate	Bromide Paper
7 μ	11 μ	18 μ	40 μ

It has been stated by H. S. Coleman and H. L. Yeagley (1940) that the intensity of light is far more important than the time of exposure, which has but a weak effect or none at all. This effect is probably confined to the conditions of low intensity and long time of exposure studied by these workers.

The effect of irradiation is diminished by all circumstances which increase the absorption of light in the photographic emulsion. It is decreased for emulsions with a high silver halide content or by dyeing a blue-sensitive emulsion with a yellow dye, such as tartrazine or naphthol yellow. The dye limits the penetration of light into the depth of the emulsion and thus localizes the image at the emulsion surface; it also diminishes the contrast of the emulsion.

213. Resolving Power. The *limit of resolution* of a photographic image is defined as the smallest distance between two point or line images which can just be distinguished by the eye at a suitable magnification. This is so chosen that the graininess of the image does not yet become too obvious and is of the order of some 30 times for normal photographic materials. The maximum number of parallel and equidistant lines which can be distinguished per millimetre is described as the *resolving power*.

For a material which is sufficiently well backed to avoid halation, the resolving power is limited by irradiation and also, to a lesser extent, by the graininess. For the same sensitive material, the resolving power, measured for images of the same density, is higher, when the exposure is heavy and development is curtailed than for short exposure and prolonged development. With materials developed for constant time, the resolving power reaches a maximum at a point situated at the lower end of the straight-line portion of the characteristic curve, around a density value of 1.0.

The following average values of the resolving

power for the different types of photographic materials will serve as a guide.

Lantern Plates	Ciné Positive Film	Fast Plates	Extra-fast Plates
75	60	50	40

With extra-fine grain emulsions, especially those used for the production of gratitudes, resolving power figures of over 1,000 lines per millimetre can be obtained quite easily. Similarly with the special emulsions used for micro-radiography, which are regularly enlarged some 300 times, 600 lines per millimetre and, exceptionally, 1,200 lines per millimetre can be resolved (L. A. Sayce, 1940).

The resolving power of an ordinary ciné positive emulsion can be increased to 100 and even to 170 lines per millimetre by impregnating it with a 1 per cent solution of chrysoidine. This diminishes the diffusion of light and limits the emulsion sensitivity to a region where the refractive index of the gelatine is raised by more than 0.2 by the presence of the dye. Unfortunately, this procedure requires ten times the normal exposure (P. Kowalski, 1944).

214. The Geometrical Accuracy of Photographic Images. The most important reason for any lack of definition in the photographic image is the amount of residual aberration in the lens used. Optical unevenness of the atmosphere, produced for example by currents of hot air, incorrect focusing or camera shake often decrease the definition. Lack of definition is also caused by the irregular nature of the photographic deposit and by the fact that irradiation tends to affect preferentially the large grains. In a print, lack of definition may be caused in addition by insufficient contact, which is more important the larger the source of light used.

Much more marked spreading of the image is caused by such defects as traces of aberration, always present even in the best lenses, and from slight faults in focusing.

Use of an emulsion of high contrast, and keeping exposure short, are means of limiting the spreading of light around each point or line and thus of improving the definition. In addition to the contractions and distortions which occur in photographic images on film or on paper because of the instability of the support, some deformation also arises in photographic images on rigid supports on account of contractions and distortions of the gelatine itself

during drying, due to the tanning action of the oxidation products of the developer. Even if drying is perfectly uniform, the relaxation of the strain set up within the emulsion layer during manufacture may cause some deformation of the image.

215. Photographic Calibration of a Sensitometric Wedge. This is best done by exposing in a printing frame containing the wedge, a piece of photographic material (preferably film) in two halves successively, the exposure time being the same, but at two different light intensities such as would be obtained by exposing at different distances from a point source. A small electric filament lamp such as a torch bulb, is a suitable source, but it is essential that its brightness does not vary during the exposures. If a voltmeter is available to ensure that the supply voltage has not varied during the whole of the exposures, a better arrangement would be to enclose the lamp in a lamp house. This can then be arranged at varying distances from a fixed piece of ground or opal glass behind which the frame is placed. In this way the calculated intensity values would not be falsified by light scattered from the walls of the room.

The ratio of the intensities of light incident on the wedge, A , can be worked out from the inverse square law (§ 11). The actual intensities are irrelevant; we only need to know their ratio. After development, which is best carried out several hours after exposure, to overcome any effects due to latent image growth or fading, one obtains two negative images of the wedge. These differ from one another merely by a displacement l which is the distance between any two points on the photographic material which have received the same exposure. The wedge constant K is then obtained from the equation $K = (\log A)/l$.

In order to measure the displacement l it is useful to rule lines at right angles to the wedge on the two prints obtained. Mark the two wedge images clearly and then cut them apart, trimming off any irregular patches that may have been formed along the boundaries. Mask off a piece of illuminated glass by means of black paper so that an area of only about half a square inch remains. Then place the two wedge images side by side on the illuminated area and slide them alongside one another, until they match exactly. The displacement l can then be found by measuring the distance of any two corresponding lines from one another.

If higher accuracy is desired, the whole procedure should be repeated with varying ratios of the exposures and the average of the values of K should be used. It is, of course, quite feasible to expose more than two wedge images on to the same piece of printing material.

Finally, one would have to determine the density at one point of the wedge. This is most easily done by exposing a material bare, with the lamp at a long distance, and again through the wedge, at a shorter lamp distance. The uniform density d obtained on the material exposed without the wedge can then again be matched to a density on the wedge image in the manner described. The relation $d = \log A^1$ holds for the point on the wedge image found in this way, where A^1 is again the ratio of the two incident intensities.

Various types of densitometers are available commercially which allow contact printing densities to be measured directly instead of by the rather roundabout method just described. These instruments are considerably cheaper than the precise apparatus employed in research laboratories or in the control laboratories of the photographic manufacturers.

Reference should be made to the trade pamphlets of the manufacturers for detailed descriptions of such instruments. We have already indicated that densitometers which utilize a photo-voltaic cell almost in contact with the density to be measured will read diffuse values directly and do not require a diffusing medium. At least for nearly neutral density strips, these densitometers are superior to visual densitometers. It is necessary to warn, however, against the use of those types of photo-electric cells which are sensitive to infra-red light, whenever the density deposit to be measured is not completely neutral.

Similar methods are used for the calibration of stop wedges. The principle here is to produce a number of density stops and thus a characteristic curve (a) with known intensities, i.e. by using the inverse square law, and (b) with the unknown intensities, i.e. through the stops of the wedge. In all this work it must be remembered, that if high accuracy of calibration is required, the tests must be carried out several times in succession and average values must be taken. In this way the effects of coating unevenness, processing errors, etc., can be overcome.

CHAPTER XVII

COLOUR SENSITIVITY, ORTHOCHROMATISM, PANCHROMATISM AND INFRA-RED PHOTOGRAPHY

216. Spectral Sensitivity of Silver Bromide Emulsions. If the spectrum from a white-light source is focused on a photographic plate or film, the density produced at the shorter wavelengths end is limited by the ultra-violet absorption of the gelatine surrounding the sensitive grains. This absorption is considerable at $250\text{ m}\mu$ and becomes almost total at $200\text{ m}\mu$. The practical limit in the other direction is $520\text{ m}\mu$ for silver bromide emulsions, and about $560\text{ m}\mu$ for iodobromides (containing 5 per cent iodide). This limit is due to the absorption of the silver halide itself, and this does not apply to the transparent emulsions used by G. Lippmann (1891) in his system of colour photography by interference methods. These emulsions are sensitive well into the red band of the spectrum. If the exposure is considerably increased, a latent image in the red band can be obtained on a normal emulsion, and even a print-out image if the emulsion has been impregnated with a nitrite. For example, the exposure at $700\text{ m}\mu$ to give identical just perceptible densities on development is 10,000,000 times that required at $400\text{ m}\mu$ (J. Eggert and M. Biltz, 1939). Thus Clerk Maxwell (1861) and L. Ducos du Hauron (1869), working with collodion plates before the discovery of optical sensitizing (1873), had to use very long exposures through green and red filters in their attempts to evolve a tricolour system of photography. Actually, the sensitivity of silver bromide measured by comparing the mass of silver liberated and the amount of light energy absorbed is almost constant throughout the visible spectrum, but the absorption decreases rapidly beyond the blue, and becomes negligible in the red (J. Eggert and F. G. Kleinschrod, 1941). Prolonged washing of the grains, which results in partial hydrolysis giving small amounts of silver hydroxide, considerably increases the red sensitivity.

Moreover, the speed varies considerably within the practical limits of spectral sensitivity; the relative exposures to give the same developed density are 20 to 1 comparing exposures at $500\text{ m}\mu$ and $400\text{ m}\mu$. The contrast, for identical development conditions, varies just as much, increasing, for example, from about 2 to 3 on

passing from the near ultra-violet ($350\text{ m}\mu$) to the violet and blue ($400\text{--}500\text{ m}\mu$). C. Fabry and H. Buisson (1924) state that the maximum value of gamma (γ_{∞}) for any given wavelength is proportional to the ratio of the density of the completely developed layer to that of the unchanged emulsion, measured at that particular wavelength.

The type of photographic emulsion which is commonly termed "ordinary," strictly speaking should be used only in the somewhat unusual case when the subject consists entirely of blacks, greys, and whites. The human eye is most sensitive to green light, especially at low intensity, and warm colours (yellows and reds) appear lighter, at equal saturation, than violets or blues. On the other hand, unless specially sensitized to colour, the photographic emulsion is chiefly sensitive to the invisible ultra-violet and the physiologically less active violets and blues (Fig. 17.1). Thus, a plate sees objects almost as they would be seen by a colour-blind person, or as we should see them through a blue filter, such as a piece of blue cobalt glass. Although red, yellow, and green objects are not always represented as black in the print obtained from a negative on such an emulsion, this is because of the reflection and surface diffusion of other colours of light from these objects.

217. Photography of the Far Ultra-violet. As explained above, ordinary commercial plates and films do not respond to radiations of wavelengths shorter than $200\text{ m}\mu$, and even at wavelengths between $200\text{ m}\mu$ and $250\text{ m}\mu$ only low-contrast images are obtainable. For photography in these regions, the following two methods may be used—

- (i) reduction of the gelatine to a minimum so that its absorption becomes negligible, or
- (ii) formation, at the surface of an ordinary emulsion, of a fluorescent screen which converts the ultra-violet light into actinic radiations not absorbed by the gelatine.

In the first method, the plates may be prepared by V. Schumann's technique (1893), or its variants (in which a fine-grain precipitate of silver bromide is deposited on a gelatine- or emulsion-coated plate), but the sensitive layer is then very susceptible to abrasion.

The second method is due to J. Duclaux and P. Jeantet (1921), who used a fluorescent layer consisting of a mineral oil. It was therefore necessary to degrease the plate before processing. According to T. Cyman (1923), it is possible to reach 58.4 m μ by this method. Nowadays, water soluble substances are used (J. Thovert, 1933), e.g. by bathing the plates for some minutes in a 1 per cent alcoholic solution of sodium salicylate, and drying in a current of air. This gives more reproducible results, and of course, does not have to be removed before development. Some manufacturers supply sensitive materials with the emulsion ready coated with a thin layer containing a strongly fluorescent compound.

218. Optical Sensitization. While investigating the cause of the heavy veil he obtained after handling collodion-silver bromide plates in orange light, H. Vogel (1873), discovered that coloration of the halide with a red dye, coral-line, made the emulsion sufficiently sensitive to green light to allow photographs to be taken through a green or yellow filter with quite reasonable exposure times. He followed this by showing that a basic blue dye, cyanine, sensitized feebly to the red, though generally causing fog and stain as well.

It was soon observed that improved results could be obtained for green-sensitization with eosin (J. Waterhouse, 1875) and even better, erythrosin (J. M. Eder, 1878) which is still used in emulsions with slight green-sensitivity, and is typical of the acid dye sensitizers.

Dye sensitization may be obtained by the addition of the dye to the liquid emulsion during its manufacture, or by bathing the plate or film in a very dilute solution of the dye.

Emulsions sensitized in this way are called *orthochromatic* (or sometimes *isochromatic*) when the sensitivity is extended to the green, or *panchromatic*, when it includes all or part of the red region. At one time, when a satisfactory method of making panchromatic plates was still unknown, some were marketed which were blue-sensitive with a very small extension in the red, but manufacture of this type of plate has been discontinued.

The emulsions sometimes called *orthopan-chromatic*, made chiefly for amateur use, are panchromatic but with low sensitivity in the red. Their spectral sensitivity is thus intermediate between that of orthochromatic and modern panchromatic emulsions.

After A. Traube (1902) had discovered the

excellent sensitizing action of an isocyanine, ethyl red, to green and orange light, E. Koenig and his collaborators, from 1903 onwards, undertook a systematic investigation of isocyanines and other dyes of the cyanine class. They prepared a series of sensitizers which made possible the manufacture of materials with greatly increased colour sensitivity, and red sensitivity extending much farther than any that had previously been available to photographers.

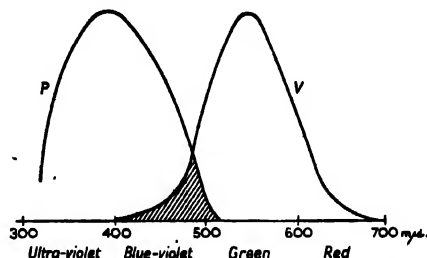


FIG. 17-1. COMPARISON OF THE VISUAL SENSITIVITY (V) AND THE PHOTOGRAPHIC SENSITIVITY (P) OF AN ORDINARY EMULSION (P) TO DIFFERENT WAVELENGTHS

The World War of 1914 caused British and American research workers to investigate the constitution and synthesis of these dyes, which had previously been exclusively manufactured in German dye-stuff factories. Their work led to new sensitizers of the same class which extended the region of spectral sensitivity more and more, even to the near infra-red. The first publications on this subject were those of W. J. Pope and his pupils (1918), then L. E. Wise and E. Q. Adams (1918), but among the numerous chemists who have contributed to the knowledge of this field, the following should be mentioned: in Germany, B. Homolka (1905), C. Scheibe (1918), W. Koenig (1922), O. Wahl (1928), W. Dieterle (1930), W. Zeh (1933); in England, W. H. Mills (1918), Miss F. M. Hamer (1923), J. D. Kendall (1930); in the U.S.A., H. L. Haller (1920), G. O. Gutekunst (1922), L. G. S. Brooker (1930); in other countries, E. Calzavara (1927), G. Schwarz (1934). Most of these workers continued to discover new types of sensitizing dye, or to improve the methods of production. These new dyes are prepared by the manufacturers of emulsions for their sole use, and the identities of the best, which are actually used, are not published. This, of course, makes publications of methods of sensitization by the user of little interest.

The discovery in 1928-30 of new sensitizers made possible the production of the modern fast panchromatic emulsions, the use of which rapidly became general in the film industry and then in most photographic studios; at the same time the substitution of thiocyanines for erythrosine considerably improved the orthochromatic emulsions of the roll-films largely used by amateurs.

219. Dyes used as Sensitizers. We shall

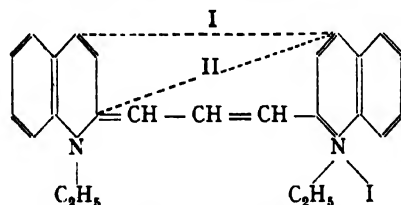


FIG. 17.2. STRUCTURAL FORMULA OF PSEUDOCYANINE

consider here only the basic dyes of the cyanine class, which are now in universal use.

Assuming that the reader has some knowledge of chemical formulae, two examples of the structural formulae of simple cyanine dyes are given. The first is a pseudocyanine, known commercially as pinacyanol (Fig. 17.2); the second, a symmetrical thiocarbocyanine, with a methyl radical on the middle carbon atom of the methin chain which links the two heterocyclic nuclei (Fig. 17.3). This type was discovered by Miss F. M. Hamer, in 1928, and has become of considerable practical importance.

For each pseudocyanine there is a corresponding true cyanine and an isocyanine, in which the carbon chain connecting the two rings is in the positions marked I and II respectively in Fig. 17.2. On the other hand, there is only one type of thiocyanine.

In the first sensitizers of the cyanine class, the bridge between the rings consisted of a single group (i.e.: CH). Great progress was made by the synthesis of the first *carbocyanines*, in which the bridge is increased by a vinylene group, to become: $\text{CH}\cdot\text{CH}:\text{CH}$. Moreover dyes can now be made in which further vinylene groups are included to make the bridge of 5, 7, 9, and even 11 carbon atoms, although the latter are very unstable. The German nomenclature is based on the number of carbon atoms in the bridge, while the other systems are derived from the number of vinylene groups ($\text{CH}:\text{CH}$). Thus a dye with 11 bridge carbon atoms is known as an

undecacarbocyanine according to the German system, but as a *pentacarbocyanine* in the other more generally used systems.

The sensitivity conferred by the cyanine dye on the emulsion extends further towards the long wavelengths the greater the number of carbon atoms between the two active nitrogen atoms (N) in the dye. Thus, a true cyanine sensitizes further than an isocyanine, which in turn sensitizes further than a pseudocyanine. Similarly, for any given type of dye, introduction of another vinylene radical into the bridge shifts the maximum sensitivity approximately 100 m μ towards the longer wavelengths, hence the continued efforts to increase the length of the chain.

While the thiocarbocyanines sensitize to shorter wavelengths than the corresponding pseudocarbocyanines, they are easier to prepare, with better yields, more stable and have less tendency to fog the emulsion. The dyes in which sulphur is replaced by selenium (selenocyanines) sensitize to considerably longer wavelengths than the analogous thiocarbocyanines; on the other hand the oxycyanines (in which oxygen replaces sulphur) are lighter in colour and sensitize in the blue region of the spectrum, and are therefore often used to increase the speed of positive, silver chloride emulsions.

There is not space to list all the known types of sensitizing dyes derived from the cyanines,

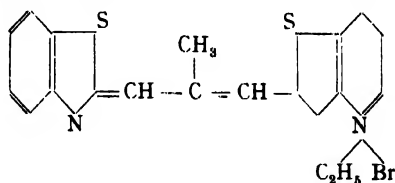


FIG. 17.3. STRUCTURAL FORMULA OF THIOCYANINE

but to give some idea of their diversity, there are sensitizers with three nuclei (*neocyanine*, *allocyanine*, etc.); dyes in which one of the quinoline or benzthiazole nuclei is replaced by a pyridine ring (*pyridinocyanines*) or by a tertiary amine (*hemicyanines*); others in which one or more of the carbon atoms in the bridge is replaced by nitrogen (*azacyanines*); and those in which the chain links one heterocyclic trivalent nitrogen atom with an oxygen atom attached to another heterocyclic ring (*merocyanines*).

220. The Mechanism of Optical Sensitization. Optical sensitization is the term generally used

for the extra spectral sensitivity induced by dyes. There is no general rule for predicting whether a dye will be a sensitizer, but all sensitizing dyes are strongly adsorbed to silver halides, through the basic nitrogen atoms in the molecule (S. E. Sheppard, R. H. Lambert and R. D. Walker, 1939). It is important not to confuse *adsorption* with *absorption*; adsorption is the attachment of a soluble compound to the surface of an insoluble body. The adsorbed compound is thus concentrated locally, and cannot, generally speaking, be removed by washing with solvent, but only replaced by another compound. Although the effects are often negligible at the surface of a comparatively coarse substance, they are of great importance when the substance is porous (for example, the activated carbon used in gas masks) or in an extremely finely divided form, because of the comparatively greater increase in surface area (e.g. a 1 cm cube has a surface area of 6 sq cm, but if this is divided into cubes of 1 micron side (0.001 mm) the surface of the same volume of material is now 6 sq m, i.e. 10,000 times as great).

The sensitivity curves of an emulsion vary according to the particular halide or mixture of halides used; the maxima, however, always coincide with those of the spectral absorption curve of the dyed silver halide (Leermakers, 1937), since the only active radiations in a photosensitive system are those absorbed by the system (C. J. D. von Grottelles, 1818; J. W. Draper, 1841). On the other hand, the chromatic sensitivity of the dyed silver halide does not correspond with that of an alcoholic solution of the dye, the sensitivity maximum always being at a longer wavelength than that of the maximum absorption of the dye solution, although it does sometimes correspond with the absorption spectrum of a layer of dye on glass, formed by evaporation of an aqueous solution (A. Schöntag, 1940).

The sensitivity curve of an emulsion varies considerably with the concentration of the dye, the soluble bromide content of the emulsion, and sometimes with the time the dye is in contact with the silver halide before the emulsion is coated and dried (G. Schwarz, 1939). The most efficient sensitization corresponds to the adsorption of the dye in a polymerized form, which gives a very intense absorption band at a longer wavelength than that of the non-polymerized dye (G. Scheibe, 1939). The presence of even a small proportion of an

organic solvent (alcohol, acetone, etc.), destroys, or at least reduces the degree of polymerization, and so prevents optimum sensitization.

At the optimum concentration, the dye is completely adsorbed to form a monomolecular layer at the surface of the silver halide grains (J. Eggert and M. Biltz, 1938). A larger excess of dye will remain free in the gelatine, thus forming a colour filter and reducing the effective sensitization.

A mixture of two or more sensitizing dyes is often used in practice, so that the maximum sensitivity of one will compensate for the minimum of another. Moreover, the sensitizing power of certain carbocyanines is considerably increased, at certain wavelengths, by the addition of isocyanine or pseudocyanine bases, although these bases may by themselves have no appreciable effect at these wavelengths. Similar effects can be obtained even with substances which are neither dyes nor sensitizers, such as aminoquinolines or basic styrene compounds (C. E. K. Mees and B. H. Carroll, 1937). Emulsions which are thus supersensitized are very stable and free from fog, in general unlike those which have been hypersensitized (§ 262).

The facts seem to suggest that the light energy absorbed by the dye is transferred to the silver halide, without destruction of the dye; thus the mechanism of latent image formation is the same as when the light is absorbed directly by the silver salt (E. Baur, 1928). The sensitizing action of a dye disappears almost completely at the temperature of liquid air, but reappears on reheating (W. F. Berg, 1939).

221. Properties of Optically Sensitized Emulsions. The sensitivity at those wavelengths where it is induced by the dye is invariably lower than the initial sensitivity, where the light acts directly on the silver halide; this is made clear if an equal energy spectrum is printed on to the emulsion. The sensitivity to blue light is always reduced slightly by dye sensitization (Lüppo-Cramer, 1940).

The dye sensitization is always more efficient on the smaller grains than on the larger, since the ratio of the absorbing surface to the mass of silver salt is so much greater. In a very fine-grain panchromatic emulsion, the speed to yellow light may be equal to, or even greater than the initial blue-light speed of the undyed emulsion, with a corresponding gain in the white-light speed. For larger grained emulsions, the speed increase is not so noticeable, except

when using artificial light, in which the red predominates.

The gamma (contrast factor), for constant development, is very low at the short wavelengths because of the absorption by the gelatine, is constant for a small interval each side of $300\text{ m}\mu$, then increases steadily up to the limit of the natural sensitivity of silver bromide towards $500\text{ m}\mu$. It then rises sharply to become nearly constant in the region of dye sensitivity. This increase has been attributed to the contribution of the more completely optically sensitized fine grains, which are thus relatively more important at the longer wavelengths, and which naturally give increased contrast (S. D. Threadgold, 1935). A certain panchromatic plate made in 1939, designed specially for tricolour work, does not suffer from this defect. Images formed by exposures to blue, green, and red light respectively all have the same contrast when developed under identical conditions.

Incorporation of substances in the emulsion which absorb the near ultra-violet (e.g. paranitroaniline) at the correct concentration have made possible the preparation of a plate suitable for spectroscopy, in which the gamma is substantially constant over the interval $250\text{--}375\text{ m}\mu$ (E. P. Davey and M. D. Gauntlett, 1945).

The reciprocity failure of dye-sensitized emulsions is such that if two differently coloured parts of a picture are reproduced as equal densities at one exposure time, they will still be equal if another time is used (J. H. Webb, 1933). In other words, reciprocity failure is the same in the various parts of the spectrum in any one emulsion.

The way in which exposures to light of different colour, given either simultaneously (A. van Kreveld, 1934) or successively (J. H. Webb, 1936), add to produce a density does not depend on the colour of the light, provided that the intensities of the exposures being compared are so chosen that they produce on their own the same density in the same time. (See § 262 for the effects of adding exposures of different intensity.)

222. Tests of Colour Sensitivity. The first idea which appears to occur to the practical photographer desiring to ascertain the colour sensitivity of an orthochromatic or panchromatic emulsion is to photograph a chart of colours, such as a sample card of paints, first with the emulsion under test, then with an ordinary emulsion, and to compare the results when developed to the same gamma. Nothing is more

deceptive than such a test. To begin with, the surfaces of all objects diffuse a certain amount of white light. It is this reflected light only which produces the images of coloured objects which appear on ordinary emulsions. Secondly, a true comparison can be made only when the exposure times are inversely proportional to the speeds of the emulsions; otherwise the relatively over-exposed negative will have a lower contrast in the blue and violet because of solarization. Finally, a large number of red pigments are slightly tinged with violet, and the effect which may easily be attributed to the red will be solely a manifestation of the extreme sensitivity of the emulsion to the violet; and even the greens and blues are always more or less impure. More reliable results can be obtained by using colour charts specially designed for the purpose. In these charts, each coloured area has alongside it an area of neutral grey of the same luminosity. The criterion of perfect colour rendering is that the grey and colour should give exactly equal densities on the material in question. In an alternative type of test-chart, each coloured area has a scale of greys of known density alongside. In this case, the density of the coloured area is matched to one of the densities given by the grey scale, thus showing equal sensitivity to the coloured light and the appropriate luminosity of neutral grey.

More convincing results can be obtained by exposing each sensitive material, with the same exposure time (but not necessarily the same light intensity) behind a chart consisting of three strips of the tricolour filters, and a fourth of clear uncoloured material. Combined with this is a neutral photographic "wedge" arranged so that the lines of equal density are perpendicular to the strips of colour filter. Then the material which is most sensitive to red, for instance, is that in which the difference between the wedges produced by white and red light is least. The difference between the wedges produced by the three colours and white do not give any significant information unless the transmissions of each filter are known and the wedge constant has been determined for the light transmitted by each filter (§ 215).

A print should be made through the strips of colour filter, each of which is double thickness for half its width, and the wedge. Then if, for example, the wedge constant for green light is 0.45, and if the difference between the lengths of the wedges obtained through the two different thicknesses of green filters is 2 cm, the

transmission factor of the filter for the total light it will pass, is the reciprocal of the number whose logarithm is $2 \times 0.45 (= 0.9)$, i.e. 0.125 or $1/8$. The analogous calculations for the other filters are made, and the relative speeds (threshold speeds; relative to the white light used) to the blue, green, and red components can be deduced. The sensitive material is exposed under



FIG. 17.4. WEDGE SPECTROGRAM OF PANCHROMATIC EMULSION

the wedge and filters, developed, and the lengths of the wedges produced by white and green light measured (l and l'). The corresponding wedge constants being k and k' , then $(kl - k'l')$ is the logarithm of the ratio of the speeds to white and green light; similarly the ratios of white to blue or red can be calculated.

223. The method which gives the most complete information is the use of a spectrograph; but it must be remembered that it is very easy for publicity purposes, to prepare completely misleading spectrograms.

If an equal energy spectrum is easily obtainable, the sensitive material is merely exposed to it, developed, and the curves of density against wavelength plotted. Alternatively, several exposures may be made with the slit progressively widened, but with the same exposure time. Thus the intensity of the light is increased step-wise, and the sensitivity curve is obtained by plotting, as a function of wavelength, the reciprocal of the light flux (i.e. slit width) necessary to give a certain developed density, e.g. 1.

In general, however, the exact spectral energy distribution is not known, and thus it is only possible to compare various emulsions. In each case the same intensity and quality of light (half-watt light, "daylight," etc.), the same exposure time, and development to the same gamma must be used. It will then be obvious from the curves showing density as a function of wavelength

which material is the fastest for each wavelength, and which is sensitized farthest towards the long wavelengths.

If a neutral black glass wedge is placed in front of the slit of the spectrograph, the resulting image of the spectrum will vary in intensity logarithmically in the direction parallel to the slit. Thus the height of the developed image will be greater the faster the emulsion, for any given wavelength, allowing for the spectral energy distribution of the light, the dispersion and absorption of the spectrograph, and the spectral transmission of the wedge. Fig. 17.4 is a positive print of such a spectrogram, with the wavelength in $10\text{ m}\mu$ automatically imprinted.

Because a plain incandescent lamp was used, which gives light rich in red and deficient in blue, the speed to red light appears greater than to blue, whereas actually, for that emulsion, it was only a fraction of the blue speed. This disproportion can be exaggerated by the glass not being neutral, or the light of even lower colour temperature, and still more by using in place of the diffraction grating a prism, which gives a spectrum in which the red end of the spectrum is seriously compressed relative to the blue.

The curves in Fig. 17.5 represent diagrammatically (with the heights in the dye sensitized regions exaggerated to show the different sensitizings more clearly) the densities on the spectrograms obtained, with a glass optical system, on various sensitive materials. (1) is an

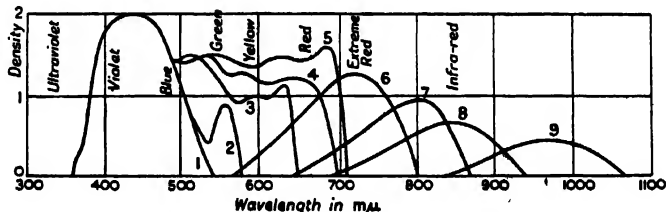


FIG. 17.5. SPECTRAL SENSITIVITY CURVES OF DIFFERENT EMULSIONS

ordinary emulsion, (2) orthochromatic emulsion of the old type sensitized with erythrosine, (3) orthopanchromatic emulsion, (4) modern panchromatic emulsion, (5) panchromatic emulsion with specially high red sensitivity for scientific work, (1 + 6) to (1 + 9) emulsions sensitized to different bands of the infra-red. It is noteworthy that the curves (3) and (5) in their behaviour at the longer wavelength ends, show the type of sensitization induced by cyanine dyes in their polymerized states. Panchromatic plates often

show a slight gap in sensitivity in the blue-green. This is done deliberately to allow inspection of the material after manufacture in dim green light. The gap is unnecessary where the materials are made and packed automatically, and statistical control by inspection of samples can be used.

224. Filters. When a photograph is taken in white light, the blue radiations are so much more effective that there is almost no difference between the negative of a coloured subject obtained on an ordinary emulsion and one on an emulsion sensitized with erythrosine. To compensate for this difference between the visual and photographic effects, the excessive activity of the ultra-violet, violet, and blue radiations must be reduced by absorbing them more or less completely by means of a filter. In particular, the ultra-violet rays do not contribute to the visible colours, and so must be completely cut out by the filter. Apart from unusual cases, the reproduction of coloured objects in monochrome in their correct tones, as for instance they would be rendered by an artist, draughtsman, or engraver, is thus only possible on panchromatic emulsions. If a filter was used of which the product of the photographic activity at each wavelength, and the intensity transmitted was proportional to the physiological activity on an observer with normal colour vision of that radiation, then the colour reproduction would be as perfect as that of a grey scale. Thus, in the ideal case, a different filter would be necessary for each emulsion, even if the latter were only slightly different. In actual practice, however, this is not necessary. The light reflected by a coloured object is never monochromatic, while any colour can be matched in photographic effect by an equal intensity of light covering quite a broad band of the spectrum. It is, therefore, quite sufficient to use a filter which gives the correct photographic representation of the three primary colours on the panchromatic material in use; the same filter can be used with all emulsions in which the spectral sensitivity is roughly the same. The tolerance would not be greater than that of the reproduction in greys of a coloured object by two equally experienced artists.

Instead of trying to produce a photographic spectral sensitivity curve that matches exactly the visual curve, it is quite sufficient to use a filter that cuts out the ultra-violet completely, and reduces the blue-violet activity to a reasonable level compared with the rest of the

spectrum. A yellow filter, whose absorption is governed by the relation of the blue to the dye-sensitized speeds of the emulsion, meets these requirements.

The sensitivities to green and red of ortho-panchromatic emulsions are usually fairly well adjusted; panchromatic emulsions, however, have a slightly higher speed in the red region, and thus tend to reproduce reds in too light shades of grey. To correct this, it is necessary to cut down the red a little as well as the blue, and thus a light green filter is used.

225. When artificial light, which is rich in red radiations but deficient in blue (e.g. from incandescent filament electric lamps), is used, the photographic activity is chiefly in the dye-sensitized region, especially in the red.

Thus one advantage of using a panchromatic emulsion (apart from the better reproduction of colour) is the maximum use of the light at one's disposal, since in this case all the light is used, whereas the larger portion of the radiations will be ineffective on an ordinary emulsion. Thus it is best to use panchromatic materials whenever a photograph is to be taken in artificial light, unless the light is very much more intense than usual (e.g. stage photography during an actual production).

It must be remembered, however, that because the light is so rich in red radiations, the representations of the reds will always be too light. If the intensity is sufficient to allow the use of a filter, one should be chosen that reduces the blue fraction only slightly, but absorbs a much larger part of the red light than one for use in daylight. When the intensity cannot be increased without difficulties arising from excessive heat generated by the lamps (e.g. in cinematography) the best solution is to compensate for the redness of the light by careful choice of the colours of the scenery and costumes, and by the actors using a make-up very different from that used in the theatre or the street.

226. The photographic effect on an ortho-chromatic emulsion, using a yellow filter for correction of the colour balance, is very similar to the visual effect obtained by examining the subject through a green filter sufficiently dense to make all other reds appear dark grey. Some manufacturers of panchromatic materials supply a *vision filter*, through which the object will appear at intensities corresponding to those obtained by photographing the object without using a filter. The effect of the photographic filter may then be observed simply by inspecting



FIG. 1. FROM A NEGATIVE ON AN ORDINARY PLATE



FIG. 2. FROM A NEGATIVE ON AN ORTHOCHROMATIC PLATE

the object through both filters. This may be useful in making a choice between several filters, as the one that will give most correct colour reproduction can then be selected.

227. Obviously, a subject containing no red objects can be photographed quite satisfactorily on orthochromatic material.

17.6, 17.7, and 17.8 respectively. The red and yellow are of about equal luminosity, and it will be seen that the ordinary plate, being insensitive to both red and yellow, has rendered the van as a uniform dark grey. The contrast has been completely destroyed, so that the lettering on the side of the van has disappeared.



FIG. 17.8 FROM A NEGATIVE ON PANCHROMATIC PLATE

Discouraged by the so-called "panchromatic plates" supplied at the beginning of the century (in which the dye-sensitization was largely illusory) many professional photographers resisted for a long time the general use of panchromatic emulsions, especially for portrait work. The cinematographic industry, which began to use panchromatic film in place of the orthochromatic in use prior to 1925, was largely responsible for the general usage of panchromatic materials, and rendered colour reproduction given by the older orthochromatic types unacceptable.

The reproduction of a red and yellow van on ordinary, orthochromatic and modern, fully sensitized panchromatic plates is shown in Figs.

The use of orthochromatic material has improved the result, but the red upper half of the van still appears too dark, e.g. it is as dark as the black tyres. This fault is corrected by the panchromatic plate, which gives an accurate reproduction of the colours on a monochromatic scale. The improved rendering of the background, especially the sky, will be noticed, particularly on the panchromatic plate.

From an aesthetic point of view, it might be argued that the modern panchromatic materials are almost too perfect, in that, if used without a correcting filter, they reduce or even completely suppress the differences between areas of contrasting colours but similar brilliances, thus removing the interest in a subject in which

the attraction lies in the contrast of colours. Of course these objections do not apply to technical or scientific work, where a uniform sensitivity throughout the spectrum is mostly required.

228. Yellow Filters. Brownish-yellow glasses, coloured throughout their thickness were used at first as yellow filters. They were practically equivalent to a combined light orange-yellow

direct dyes (used especially for dyeing "Cellophane") are very permanent, but their absorption bands are shaded off and they can be used for decorative purposes only. Most of the dyes transmit the near infra-red and sometimes the far infra-red as well. This extraneous transmission (e.g. as shown by filter No. 58 in Fig. 17.9) does not matter when it occurs in that part

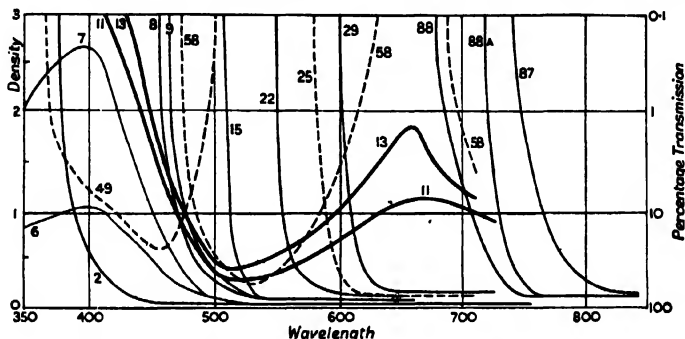


FIG. 17.9. SPECTRAL ABSORPTION CURVES OF SOME COLOUR FILTERS

The minimum of each curve corresponds to the maximum transmission.

filter and a smoked glass, the latter absorbing all radiations uniformly without any useful effect. The only really effective filters which could be prepared at that time were made of coloured liquids (solutions of metallic salts, or of artificial dyes) contained in glass cells with parallel sides. In spite of the advances made in their manufacture, filters of coloured glass are not so uniform nor so transparent, at equal efficiency, as filters of dyed gelatine. Their one advantage is greater stability and strength. A reputable maker of yellow glass filters states that he scraps filters of which the uniform absorption exceeds 15 per cent (equivalent to the incorporation of a neutral density of 0.07).

The enormous progress made in the methods for the preparation of gelatine filters (coloured gelatine unprotected or sealed between two pieces of plane-parallel plate glass) has gradually led to the manufacture of an enormous range of colours in this type of filter suitable for many purposes. In addition, the range of satisfactory dyed-glass filters is now wide enough to cover all normal needs. The basic dyes (§ 752) are usually those that have sharply cut absorption bands, but they are rather unstable and, therefore, acid dyes are preferred for preparing colour filters. These have almost as sharp an absorption, and are far more stable. The

of the spectrum to which the sensitivity of panchromatic emulsions is negligible.

These filters are completely defined by the number of grains per square metre of the given dye they contain (a unit suggested by Hübl). The effect of a filter is commonly represented by plotting density or transmission against wavelengths. In Fig. 17.9, the curves for several of the most frequently used of the hundred or so filters supplied by one maker are given, the density being shown on the scale at the left and the percentage transmission on the right. The curves represent: a colourless aesculin filter which absorbs almost all the ultra-violet (No. 2), several yellow filters of increasing depth (6 to 9), two yellow-green filters (11 and 13) differing by the proportion of extreme red they transmit, and three filters which all transmit the infra-red but a variable proportion of the far red (87, 88, and 88A) and several filters not often used, including the trichromatic filters (49, 58, and 25). It should be noted that the special yellow filters for use with the colour processes employing a coloured mosaic or réseau are designed to equalize the photographic effect in the three main spectral bands, and thus in general transmit too much violet for use as a filter with orthochromatic emulsions.

The optical theory of colour filters, with consideration of their placing, etc., will be found in §§ 119-20.

229. The Factors of a Colour Filter. The use of a coloured filter, which absorbs a greater or less proportion of the photographically active rays, necessitates an increase in the time of exposure, or area of the diaphragm in the case of cinematography, where the exposure time is fixed, to obtain the same densities when exposing on a neutral grey scale, with and without the filter. The ratio of the exposure times or the stops with and without filter gives the *coefficient* (or *multiplying factor*, or, simply, *factor*) of the filter for the particular type of emulsion and illumination employed.

Many photographers imagine they have completely defined a colour filter by giving *one* factor. Now, two filters having the same factor with respect to a *given emulsion*, and under given conditions of illumination (that is to say, two filters through which the optimum times of exposure will be the same multiples of the optimum times of exposure without the filters), may have very different factors, with respect to another emulsion or under different conditions of illumination, and under the same working conditions these filters may produce very different results.

The mistaken idea that a filter has only one factor under all circumstances dates from the days when the so-called "yellow filters" were equivalent to a yellow filter with comparatively little absorption and a fairly dense grey filter. Thus, the combined factor, always very high, was almost constant under different conditions because the factor of a neutral grey filter is constant. Nowadays, most manufacturers of filters take the precaution of giving a list of average filter factors for each type of filter under various conditions.

When viewing objects by daylight, the relative effects of the three colours on the eye are in the following approximate proportions: red, 34 per cent; green, 60 per cent; and blue, 6 per cent. The ideal filter reduces the respective effects on the sensitive emulsion to these proportions. We can see from this that the most suitable filter for a certain type of emulsion will not be as suitable for another very different type of emulsion.

Consider the case of a panchromatic emulsion, equally sensitive to the three groups of spectral radiations.

If we assume that in daylight the energy is

distributed about equally between the three large spectral regions in question, i.e. 33 per cent for each, we can say that the intensities of each group will be converted to the desired relative values by a filter transmitting 51 per cent of the red, 90 per cent of the green, and 9 per cent of the blue. This yellowish-green filter thus transmits altogether half the white light, and this will be compensated if we double the exposure.

Suppose we use the same filter with an orthochromatic emulsion practically insensitive to the red, and having a spectral sensitivity to the green and blue of 20 per cent and 80 per cent respectively. Apart from subjects consisting entirely of blue and greens, the result cannot possibly represent the visual impression, since the red radiations, so active to the eye, have no action at all on this emulsion.

With a filter transmitting 90 per cent of the green and 9 per cent of the blue, the photographic effect through this filter will be: for the green (0.20×0.90), or 18 per cent of the total effect when the filter is not used, and for the blue (0.80×0.09), or 7.2 per cent, making altogether 25 per cent. To compensate, we must in this case give four times the exposure. Further, while the effect of the blue in the formation of the image on a panchromatic plate represents only 6 per cent of the total effect, it represents in this case $(7.2/25.2) = 28.5$ per cent of the light-energy utilized. The efficiency of the filter is thus considerably reduced.

Finally, let us suppose that the same yellow filter is used with an ordinary gelatine-bromide emulsion, in which 2 per cent of the image is formed by the green and 98 per cent by the blue. The introduction of the filter reduces the effect of the green to (0.02×0.90), or 1.8 per cent, and of the blue to (0.98×0.09), or 8.8 per cent, altogether 10.6 per cent. To obtain the same image of a grey scale we must expose nine times as long as without the filter. The effect of the blue in the image thus formed amounts to $(8.8/10.6)$, or 83 per cent of the light-energy utilized. The efficiency of the filter in this case is thus practically nil.

Whilst, relative to a constant illuminant, a given yellow filter may have factors equal to 2, 4, and 9 respectively, for the various emulsions considered, a neutral grey filter transmitting uniformly 50 per cent of all radiations has a constant factor of 2, whatever the emulsion, and an efficiency of 0.

We shall discover other variations in the

value of the factor if we consider how the ideal panchromatic plate behaves, in conjunction with a greenish-yellow compensating filter, relative to various kinds of artificial illuminants. The data for various cases are given in the following table.

	Mercury vapour lamps	Arc lamps	Gas-filled lamps (half-watt)
Approximate percentage proportions of rays of different colours in the light-source	Red — Green 10 Blue 90	60 25 15	61 32 7
Proportion of rays of different colours transmitted by the filter relative to 100 white light without filter	Red — Green 9 Blue 8.1 Total 17.1	30.6 22.3 1.3 54.4	31.1 28.8 0.6 60.5
Factor of filter	5.9	1.8	1.65
Net effect of blue in formation of image	47%	2.4%	1%

In short, the factor of a filter is higher the more active the absorbed radiations in their effect on a given emulsion, or the greater the proportion of them in the light emitted by the illuminant used.

It will also be seen from this table that the yellow filter may even over-correct the colour balance. Thus, when used with arc lamps or half-watt light, the percentage of blue light that is effective is so small that the results are just as far from the true rendering of the colour as those of an unsensitized emulsion.

230. Experimental Determination of the Factors. The only elements of the subject which retain their relative luminosities after introduction of a colour filter are the whites, neutral greys, and blacks. Each value of the factor of a colour filter is, thus, the ratio of the two exposures, which, with and without the filter, give images of the same densities, all other working conditions being the same (same emulsion, same illumination, same development, etc.). Moreover, if the results are to be of practical value, these conditions, exposure time, development time, etc., must not be very different from those actually used in practice. This is especially important in determining the factors for tri-colour filters. For instance, if the development time is considerably increased for the negative made with the blue filter, so as to obtain equal gammas on all three negatives, errors of up to 50 per cent may result if this is not taken into account in working out the factor. Deviations

from the reciprocity law can also cause grave errors in the values obtained if the test conditions are very different from those of practice. For example, in a series of experiments made with the same emulsions and using the same artificial light and exposure time (1/10 sec.) the values obtained for the blue, green, and red filters were 17, 7, and 4 respectively. When the stop was kept constant, and the exposure time varied between 1/10 and 10 sec, the values were 16, 7, and 4 (J. L. Tupper, 1940).

In determining a filter factor, it is very important to make certain whether the increase in exposure will be brought about by an increase in *time* or in *intensity* of exposure. In general, the filter factor relating to time of exposure will be the larger because of reciprocity effects.

In the absence of more accurate means, a subject, such as a photograph on paper developed to a neutral tone, or a graded scale on black carbon tissue is chosen, and tentative exposures are made until we obtain through the filter an image equivalent to that obtained without the filter.

The cost of these trials can be greatly reduced by making them on different parts of the plate or film for the use of which we wish to determine the factor. The parts of the sensitive film not being used in a test are covered successively by means of masks suitably placed in the camera, or the photograph chosen as subject may be mounted on a slide in front of a deep box lined with black velvet, so as to afford an absolutely black background. Several exposures can then be made, sliding the original between each, without any other adjustment.

231. If a neutral grey wedge is available, an accurate determination of a filter factor may be made as follows (L. P. Clerc, 1938). Four strips of the sensitive material are given the same exposure time through the sensitometric wedge using exposure times and quality of light fairly close to those used in practice (e.g. daylight must be replaced by one of the blue-glass electric bulbs called "daylight lamps"). Strips I and II are given the same exposure, while strips III and IV are both given 1/25 of that exposure (e.g. by moving the lamp to five times the distance from the plate, and giving the same exposure time). Strips I and IV are exposed to the full white light, but the other two are exposed through the filter. Then the difference in length between the wedges produced on strips I and IV corresponds to differences in the wedge density of 1.4 (log 25 = 1.4) for

white light, while that on strips II and III corresponds to the same density for the filtered light. It is thus possible to calculate the wedge constants K_W and K_F , as in § 215.

Now comparing strips I and II or III and IV, two equal low densities on the wedges are matched, and the distances l_W , l_F from the end of the wedge measured. Then the equal densities on the copies were produced by equivalent densities of the wedge, and their relationship is $l_W K_W = l_F K_F + \log C$. Thus the filter factor is the number whose logarithm is equal to $l_W K_W - l_F K_F$.

To find the factor for the filter with another emulsion, if the same wedge and lamp are used, it is only necessary to make strips I and II or III and IV, as the wedge constants are already known.

232. Orthochromatic Emulsions in Practice—Portraiture. The essential part played by the red radiations in the colouring of the face is shown by the complete alteration of the colours in the light of a mercury arc. The orange coloration of the skin, with spots and red streaks, yellow freckles, and small reddish veins running along wrinkles, are not particularly noticeable on anyone's face, but are considerably accentuated by a photograph on an ordinary emulsion. In order to avoid rendering the skin too dark, the photographer over-exposes, thus sacrificing detail and gradation in light clothing.

The use of an orthochromatic emulsion with a yellow filter considerably assists the rendering of blonde or red hair, blue eyes, the purplish shadows which give the eyes their relief, lips, and certain colours of the dress, but still leaves a great deal to be retouched, e.g. minute defects in the skin, wrinkles, etc. The use of panchromatic plates, however, leaves nothing for the retoucher to do beyond taking out mechanical defects in the sensitive film, and the "rejuvenescence" of the sitter, often necessary but obviously not capable of accomplishment by any photographic process. It is very pleasing to disguise the signs of increasing age, and it is certainly the use of a panchromatic emulsion with appropriate illumination that avoids this inevitable change more satisfactorily than the use of ordinary emulsions.

In daylight, a panchromatic plate or film should be used with a fairly light-coloured filter, either yellow or greenish-yellow according to whether the emulsion is more sensitive to green than red or vice versa. Under artificial

lighting conditions, where there is an abundance of red but little blue light, the filter used should only absorb red, i.e. a light blue or blue-green filter.

It is interesting to note that the photograph of a negro on an emulsion sensitive to infra-red produces, as regards skin pigmentation, the almost complete illusion that it is the photograph of a fair-skinned person.

233. Landscape, Aerial Perspective and Mist. Among pictorialists in photography—those who exercise a large measure of personal control and produce works which owe nearly as much to the brush as to the photographic process—orthochromatic materials are often considered useless for landscape photography. But for those who wish to obtain by purely photographic methods a tone rendering as near as possible to the interpretation of an artist using only black and white, the only process for photographing a landscape is on an orthochromatic or panchromatic emulsion with an appropriate colour filter.

It is worth remarking that it is sometimes possible to obtain a photograph of a multi-coloured landscape on an ordinary emulsion, using exposure times considerably greater than the minimum necessary, which differ little in their colour rendering from those obtainable on orthochromatic or panchromatic emulsions. This is because the subject is reflecting quite a large part of all the radiations besides those of the individual colours (O. Bloch and W. H. Dimsdale, 1938). This obviously does not apply to such subjects as stained-glass windows, close-ups of highly coloured objects against almost neutral backgrounds, or photographs in artificial light, where the red light predominates.

234. Two things have to be considered in the use of orthochromatic emulsions in landscape work: the rendering of distance, and the interpretation of different colours.

In a negative of open country, taken without special precautions, the image of the distance is always shrouded in a more or less dense mist, in which details disappear. At the time of taking, these details were probably easily perceptible to the eye through the bluish haze near the horizon.

Even when the atmosphere appears to us absolutely clear, it is in fact a turbid medium, the effect of which is greater in proportion to the space between distant objects and the lens. For instance, after rainfall, when the air appears clear, it is in fact turbid with microscopic drops of water in suspension. Like all

turbid media, it is practically transparent to infra-red rays, but stops in increasing proportions greens, blues, violets, and ultra-violet rays, i.e. the shorter wavelengths. These radiations are not, however, absorbed appreciably, but diffused in the same way as any light is diffused by a fog or mist; hence the peculiar appearance of photographs obtained by ultra-violet radiation alone (§ 15).

The relative intensities of the light diffused in normally clear or hazy atmosphere are inversely proportional to the fourth power of the wavelength (Lord Rayleigh). This is the reason for the blue colour of the sky. When passing from ultra-violet 350 to infra-red 800 $m\mu$, the intensity of mist is therefore reduced in the relation $(8/3.5)^4$, i.e. 27 : 1. Particles of diameter greater than 5μ diffuse all radiations uniformly.

The following observations serve to prove the selective properties of the atmosphere. Dark objects a long way off always appear bluish, and snow, golden. The sun appears redder the lower it is on the horizon because it is then seen through a greater thickness of air. The pure blue of the sky at the zenith in fine weather is due to the light diffused by the atmosphere, and if the sky passes to a bluish white towards the horizon, it is because the light is then diffused by a thicker layer of a more diffusing medium (by reason of the dust, always more plentiful near the ground), the blue radiations being accompanied, but in reduced quantities, by the other components of white light. Finally, in a fog, shadows appear blue, and a lamp appears to emit red light as soon as one walks away from it.

The haze of distance and the progressive weakening of the coloration form the principal factors in *aerial perspective*, which gives one an idea of the respective distances of the various elements of a landscape. The use of an emulsion which is only sensitive to the blue, violet, and ultra-violet, necessarily exaggerates the effect, which many artists have used to excellent advantage but which cannot be an advantage in straightforward photography. The use of panchromatic plates with a suitable filter cutting off all light of wavelengths below 500 $m\mu$ (e.g. filter No. 15 in Fig. 17.9) will give photographic detail equal to that visible to the naked eye, while the use of the red rays only, or even the infra-red, exaggerates the contrasts of the distance, the photograph recording details which could not be seen with the naked eye at

the time of exposure. An example of this is given in Figs. 17.10 and 17.11 which are two photographs taken at the same time on orthochromatic emulsion with a yellow filter, and an emulsion sensitized with a neocyanine using an infra-red filter (No. 88 in Fig. 17.9). The extra detail on the distant hills is apparent, but the limiting distance for infra-red rays is rarely more than double that for direct vision—a little different from the miraculous claims of the "scientific" writers in the daily and popular press (§ 238). The photographs taken from the stratosphere by balloon made by A. W. Stevens of the U.S.A. over distances of some hundreds of miles were obtained in a region where the air is exceptionally clear.

There are two applications of photography in which atmospheric haze is the cause of special difficulties—photography at a great distance with telephoto lenses of high magnification, and aerial photography at great altitudes. In both cases the subject is entirely situated in the distance, of which the bright parts will be yellowed and the dark parts blued. Hence, considerable reduction of contrast is caused so that the image on the negative is very faint, a practically uniform haze being chiefly recorded. To reduce or remove atmospheric haze, in this case, filters of greater absorption than the usual orthochromatic filters must be used, although some improvement is obtained, especially on panchromatic materials, with the ordinary filter. Even a colourless filter that cuts out the ultra-violet rays (No. 2 in Fig. 17.9) gives a considerable improvement. The aesculin filters, however, must be protected by a lens hood from direct light other than that from the subject, as they give a slight blue fluorescence, which may cause some light general fog (A. Bäckström and R. Johanson, 1936).

In *telephotography* long exposures have to be made, owing to the low intensity of the greatly magnified image, and one is forced to use a stout camera and a heavy rigid tripod, so that a deep yellow filter may be used, e.g. a filter having an absorption represented by curve 15 in Fig. 17.8. This transmits only the green, yellow, and red, and has a factor somewhere between 8 and 20, depending on whether a panchromatic or orthochromatic emulsion is used with it.

In *aerial photography*, where the circumstances always necessitate a very short exposure, it is not generally possible to use filters of this degree of absorption, but the contrast of the image will



FIG. 17. LANDSCAPE PHOTOGRAPHED ON ORTHOCHROMATIC
EMULSION WITH YELLOW FILTER

(Photo by Hugo van Wadenoyen, from *Expos*)



FIG. 18. SAME LANDSCAPE PHOTOGRAPHED ON AN INFRARED
SENSITIVE EMULSION WITH A DEEP RED FILTER

(Photo by Local Press)

be greater, and in consequence its definition improved. The English and American air services, using very wide-aperture lenses and high-speed panchromatic films, having high sensitivity in the red, have been able, with the help of reddish-orange filters (Nos. 22 and 25 in Fig. 17.9), to obtain excellent photographs of ground covered with a light fog, through which only occasional details of the earth appeared visible when flying over it. One cannot hope, however, to pierce an opaque fog by using red or infra-red radiations, while the low speed of infra-red emulsions allows their use in aerial photography only under exceptional circumstances.

235. The use of a light yellow filter, however light it is, suffices to increase the contrast between the white clouds and the deep blue of the sky, and at the same time to reduce the contrast between the sky as a whole and the ground. This reduction in contrast is probably more important than the colour correction; without the filter, the whole sky is over-exposed and thus the difference between the brightnesses of sky and clouds does not register on the emulsion. A light yellow filter (No. 6 in Fig. 17.9) of factor of 2 at most on a panchromatic emulsion, or 3 on an orthochromatic emulsion, reduces the sky to its correct value relative to the earth, whilst still allowing the camera to be used in the hand. The greens of spring will, at the same time, be greatly lightened, but the greenish-blue foliage of fir trees will not be greatly improved—especially if one uses an orthochromatic emulsion having a minimum sensitivity corresponding with the greenish-blue. A deeper yellow filter (No. 7 in Fig. 17.9), used with an orthochromatic emulsion, for which it has a factor of 3 to 4, assures a satisfactory correction of the blue-greens and also of autumn foliage, which are practically impossible to render correctly on an emulsion insensitive to red.

For high-speed panchromatic emulsions, a greenish-yellow filter (No. 11) with a factor of 4 gives the best colour correction. Deeper filters always darken the sky too much, while they have such high factors that a stand must be used for the camera, unless the lens has a very wide aperture.

236. **Photography of Coloured Objects.** The photography of coloured objects presents considerable difficulties in some cases, especially when the "effects" of the subject to be reproduced are entirely dependent on the contrast

of colours, the tonal contrasts being very weak, as is the case, for example, with tapestries and many modern pictures. An isochromatic rendering, in the strict sense of the word, which represents each colour by an intensity of grey proportional to its luminosity, may cause the design of the object reproduced to disappear almost completely, whilst a photograph on a non-colour-sensitive plate will ruin both the tones and the forms, a pattern in green and red being rendered as a uniform black. No fixed rule can therefore be given. Taking into consideration the type of subject and the result required, a different filter must be chosen in each case, so as to render each colour with a luminosity which differentiates it from the adjoining colours.

In the more general case, when the subject presents both contrasts of colour and tone, better results can often be obtained by using a panchromatic plate and a yellow filter, rendering each colour by the luminosity with which it is customarily seen by the eye. With ortho-panchromatic emulsions, filters such as Nos. 8 or 9 in Fig. 17.8 will be satisfactory, while for a panchromatic material of high red sensitivity, No. 13 is more suitable. If this general correction leads to neighbouring colours being rendered in the same tone, it may be advantageous to lighten the reds a little relatively to the greens, in order to compensate for the normal attraction of the eye to the reds. A perfect colour rendering is possible only if the filter absorbs the near ultra-violet transmitted by glass, and if the emulsion is not sensitive to infra-red. Some whites are, as a matter of fact, rendered as blacks if ultra-violet has a dominant influence, and infra-red renders as white or as a very light grey a large number of colours and even certain blacks.

The photography of almost monochromatic objects taken by themselves must be treated in a very different way.

The practical rules follow from the following principles—

1. To render the various intensities of a single colour by graded densities from black to white (an object consisting only of intermediate shades between a pure colour and white), the photograph must be taken by means of rays absorbed by the colour in question, but the absorption must be complete only in the maximum density of the colouring. For example, for a piece of Delft ware, having blue decoration on a white ground, a panchromatic

emulsion and an orange or red filter (Nos. 22 or 25 in Fig. 17.9) should be used. An application of this principle has been made by E. Calzavara (1927) to the photo-micrography of histological specimens coloured by a cryptocyanine (sensitizer for the infra-red), the photographs being recorded entirely by the infra-red on emulsions sensitized by the same cryptocyanine, with interposition of a filter absorbing all other active radiations.

2. To reproduce, by graded densities from black to white, the various luminosities of a uni-coloured object, presenting only intermediate shades between a saturated colour and black, use must be made of only those radiations which are most completely reflected by the colour of the object. For example, to bring out just the veins of a piece of mahogany furniture (without considering the appearance of the wood as a whole) a panchromatic emulsion should be used with a red filter (Nos. 25 or 29 in Fig. 17.9). Following this principle, in the case of the photomicrography of many insects, infra-red radiations are used, since the dark-brown epidermis which absorbs strongly light of the visible wavelengths, is transparent to infra-red.

3. Maximum contrast (Case 1) being incompatible with maximum detail (Case 2), if detail cannot be sacrificed to contrast, or vice versa, that is to say, if the subject consists of both light and dark shades of the same colour, a compromise must be made between the two contradictory conditions given above.

These conditions are fulfilled with sufficient approximation by choosing from a set of three-colour filters that through which the subject appears to greatest advantage when seen through a "vision filter" and preferably two thicknesses of the filter in question. It must be borne in mind that the results obtained with a panchromatic film and a blue filter will be practically identical with those on an ordinary film without using a filter.

237. **Photography with Infra-red Rays.** It should be borne in mind that cameras used for infra-red photography must not contain any material transparent to these rays, unless covered with an opaque coating (made with lampblack, for instance). While all metals, even the thinnest sheets, are perfectly opaque, many types of wood are more or less transparent in thicknesses under 1/8 in. (mahogany and deal particularly so). Unless containing opaque fillings, ebonite, bakelite, and vulcanized fibre are transparent, as are also leather camera

bellows and paper. Moreover, lenses are not usually achromatic for infra-red rays, and the correct focus must be found by making trial exposures. The increase in focal length is usually of the order of 0.3 to 0.4 per cent.

There are commercial infra-red emulsions of several types with spectral sensitivities corresponding to the curves (6) to (9) in Fig. 17.5. It will be seen that they have comparatively low speeds in the dye-sensitized band and are practically insensitive in a more or less extensive area comprising most of the green and the yellow. The actual limit of recording of infra-red light reached appears to be 1,350 $m\mu$, obtained by exposing a hypersensitized plate for 11 hours to a solar spectrum.

Moreover, theories developed by G. Kornfeld (1938) indicate that the limit cannot be raised above 2,000 $m\mu$, and probably not above 1,500 $m\mu$. Until the fairly recent discovery of infra-red sensitizing dyes, photographs by these rays were obtained by two indirect methods. The use of a phosphorescent screen allowed H. Lehmann (1906) to reach 1,541 $m\mu$, and J. Waterhouse (1873) used a prefogged emulsion, which he impregnated with a desensitizing dye; the fog was destroyed by the action of infra-red rays. By this method, sensitivity to rays of 1,130 $m\mu$ was attained on very thinly coated emulsions, impregnated with malachite green or iodine green dye.

Whereas plates and films sensitized to the near infra-red can be kept for several months without special precautions before becoming fogged to a troublesome extent (provided that their packing includes a sheet of metal foil), those sensitized to longer wavelengths must be stored in a refrigerator, or, in the case of those of extreme sensitivity at the temperature of carbon dioxide snow (-95°F.) almost up to the moment of using (W. Dieterle and W. Zeh, 1935). Even so they undergo a progressive diminution of speed which, however, largely returns on hypersensitization (§ 226).

These sensitive emulsions are the slower the farther their sensitivity advances into the infra-red. The exposure factor may reach 400 for photography with a black filter (through which the sun appears red) Nos. 87, 88, 88a in Fig. 17.9. This number is only approximate, for there is no proportionality between visible intensity and infra-red intensity in daylight (G. B. Harrison, 1932). For a portrait group taken in darkness, the subjects receiving only infra-red light given by incandescent lamps

through black filters, the power of the lamps must be about 1 hectowatt per square metre of floor in order to permit an exposure of 1 second at $F/3.5$. In such photographs (the same result being obtained if the filter is mounted on the lens) faces appear chalky with colourless lips, the eyes are shown as black circles, and all the features are very accentuated.

With an exposure of a few hours it is possible to photograph in complete darkness an electric flat-iron heated at its normal rate, or an object, such as a plaster bust, "illuminated" by two such irons.

238. We have already mentioned (§ 234) the applications of infra-red to long-distance photography. Highly exaggerated statements have been made as to the possibility of photography in a fog. In a slight fog the range of infra-red photography is scarcely twice that of the visual range (equal to that of photography in a red light), and the increase in range is almost nil in fog. In particular, no success has attended attempts made to facilitate navigation in a fog by taking infra-red photographs and examining them in a very short time afterwards.

We cannot enumerate here the very numerous technical and scientific applications of infra-red

photography, nearly all of which are based on the difference of transparencies and reflecting power towards infra-red and towards daylight. One of the most interesting is the use of infra-red light to take photographs of the machines used for coating photographic emulsions while actually in use, since the ordinary emulsions are not of course fogged by the infra-red light.

Portraits taken by infra-red light show some unusual effects; the skin is transparent and allows the roots of the hairs in the beard to be seen. Thus, a man who has just shaved appears to have a beard of several days growth. Moreover, the veins are visible, and this fact has been made use of in diagnosing varicose veins before they become apparent to the eye. While carbon, in the different forms in which it is used in painting, behaves like black, as also do certain mineral pigments (iron blues, copper greens, and all mixtures in which they occur in large proportion), most usual pigments behave like white or light grey, hence there is an almost complete suppression, in the photograph of a coloured object, of everything that is not a black or a shadow, while several thin fabrics are completely transparent.

CHAPTER XVIII

PLATES, FILMS, NEGATIVE PAPERS, AND SPEED RATINGS

239. Supports for Sensitive Coatings. The terms plate, film, and photographic paper are applied to photographic products resulting from coating sensitive emulsion on to glass, flexible transparent material, and paper, respectively.

In Daguerreotype, which was the first practical photographic process, a thin sheet of silver-plated copper was used as the support, and the sensitive coating was made by treating the surface of the silver with iodine vapour. Later, in the case of ferrotype, a process still used by itinerant photographers, sheets of iron covered with black varnish and then coated with a collodion emulsion were developed to give an image appearing more or less white on the opaque black ground, thus forming a direct positive.

Many attempts have been made to use aluminium or steel plated with nickel as a support for gelatine-bromide emulsions, either as a flexible band for amateur cinematography (the image being observed or projected by reflection), or as a rigid plate instead of glass in accurate photogrammetric work, where measurements are made directly on the negative and where it would be advantageous to make use of sensitive materials as rigid as glass plates but less fragile.

240. Glass. The glass used in the production of photographic plates is specially manufactured. It must be fairly flat, of uniform thickness, almost colourless, and as free as possible from bubbles or black spots. These qualities are rarely united in one glass, even in the highest qualities. The sheets of glass, received in crates, are sorted according to thickness and quality and stored for distribution as required. Except in the case of very large plates the size required is not the size coated. Medium-size plates are prepared by coating a sheet which is twice or four times the size required, afterwards cutting at right angles, with automatic machinery. For small plates, a sheet corresponding with eight or more is used. For certain scientific purposes emulsions are coated on plate glass which cannot be cut by automatic machinery owing to its thickness, and so must be cut by hand. The glass is cleaned on both sides with alkaline solutions on machines having either rotating or reciprocating brushes. The plates, carried on endless

belts, are rinsed in a large amount of water and then coated on the concave face, on which the emulsion will ultimately be coated, with a *substratum* consisting of a small quantity of gelatine in strong alum solution. Drawn glass, which is sometimes used, is without general curvature, but has wide though slight channelings, which are visible by highly oblique light. In any case, the drying of the gelatine coating causes a bending of the glass of which the emulsion-coated side becomes concave. The substratum causes the emulsion to adhere to the glass; the plates then pass through a tunnel through which a current of warm air passes, and arrive at the end dry and ready to be transferred, on wooden racks, to the coating room.

It is almost impossible to re-coat glass from old photographic negatives. Glass is not, as is commonly supposed, an inert material. Under many influences (light, atmospheric action, chemical treatment, etc.) it is susceptible to many changes, of which the most curious is one shown frequently by photographic plates. After stripping off the old emulsion and cleaning with great care, even to the extent of using concentrated and boiling nitric acid and alkalis, some plates will give a more or less complete rendering of the original image when the glass is silvered or when it is coated with fresh emulsion. (In the latter case, development of the fresh emulsion is necessary.) It may be supposed that the presence of ultra-microscopic particles, probably of metallic silver in solid solution in the glass, are the cause of this phenomenon.

The plates, loaded end-to-end on to the endless band of the coating machine, pass first under a coating trough, which distributes over them a uniform layer of liquid emulsion, and then through a cold tunnel, where the emulsion sets. The plates next pass to another endless band which, through moving more quickly than the first, separates them. On reaching the unloading station they are placed on racks for transport to the driers (drying rooms or continuous conveyor driers).

After drying is complete the plates are examined, cut up, and wrapped, etc., for delivery to customers.

241. Photographic Plates. The sheets of glass used in the manufacture of photographic plates are divided, according to thickness, into three classes—

Extra thin glass	$\frac{1}{160}$ to $\frac{1}{120}$ in.
Thin glass	$\frac{1}{160}$ to $\frac{1}{80}$ in.
Ordinary glass	Above $\frac{1}{80}$ in.

As the *lower* limit for the internal dimensions of negative holders and plate carriers is the same as the nominal dimensions of the glass (with a tolerance of 1 per cent *at the most*) the nominal dimensions may be considered as the *maximum* dimensions of the sensitive plates. The cutting tolerances, at the most equal to 1 per cent, can be allowed only within the nominal dimensions. For lengths less than 8 in. a cutting tolerance of from six to eight hundredths of an inch is allowed. In practice an attempt is made to maintain a difference of less than $\frac{1}{20}$ in. between the nominal and the real dimensions. In order that the plates may be effectively held in the plate holder, the dimensions of the image (measured between grooves or angle blocks) must be 5 per cent less than nominal. The American standard Z38.1.30-1951 allows for plates below and up to 10×8 in., a tolerance of $\pm \frac{1}{64}$ in. and for larger sizes a tolerance of $\pm \frac{1}{32}$ in.

Photographic plates are usually sold in boxes of a dozen. Sizes from whole plate ($8\frac{1}{2} \times 6\frac{1}{2}$ in.) upwards are supplied in boxes of six. In the interior of the boxes the plates are packed face to face in groups of 2, 4, or 6, often with edge spacers between the plates so as to keep the emulsions apart, wrapped in red or black paper, and the various packets are themselves wrapped in black paper.

242. In addition to trade particulars (trade mark, type of plate, etc.), the label on the box always has on it the *emulsion batch number*, so that the maker, in case of claims (Chapter XXXII), can refer to the works register to find full particulars of the emulsion in question, together with the results of the tests made of the batch. All claims relating to a supply of plates should give the emulsion batch number, and be accompanied by the reference slip (which has on it the number of the examiner), which will be found inside the box. We would urge the photographer to examine his conscience very carefully before blaming the maker for failures, which, in the vast majority of cases, have been shown to have resulted from some incorrect manipulation

during the course of the operations. The batch number is, moreover, of much greater value to the user than is generally believed. Two successive batches of the same formula cannot be absolutely identical in spite of all the care which is exercised, and a change in number indicates a variation in one or more of the characteristic properties of the material (slight variation in sensitivity and, for panchromatic emulsions, variations in the relation of sensitivity to the different colours; variation in speed of development, which may be considerable, and is the chief variant from a practical point of view). Photographic plates maintain all their qualities for a period of time much greater than a year, provided they are kept under reasonably cool and dry conditions, and it is advisable, when the quantity required can be estimated, to take a sufficiently large stock of plates with the same emulsion number to last for from three to six months. In this way one can be sure that all the plates used will behave similarly.

243. Flexible Supports. The flexible supports on which the emulsion may be coated are obtained by evaporation of a concentrated solution of a cellulose ester and a suitable plasticizer, which itself is a non-volatile or very slightly volatile solvent.

At first, celluloid, which is a solid solution of cellulose di-nitrate in camphor was exclusively employed. Other less inflammable supports are now extensively used. These consist of solid solutions of cellulose acetates or mixed esters, notably acetate-propionates, acetate-butyrate, acetate-laurates, etc., which are less permeable to water, in a plasticizer which is often an ester, e.g. tri-butyl, tri-phenyl, tri-inisyl phosphate or phthalate. For several years experiments have been made to replace cellulose esters by various synthetic resins such as polyamyl alcohols, urea-formaldehyde resins, etc.

In spite of the inconvenience of its inflammability, cellulose nitrate has until recently been most widely used as a flexible support for photographic emulsions. The non-inflammable cellulose diacetate and the mixed esters are used for substandard (less than 35 mm wide) ciné film and for radiographic "safety" film for use in hospitals. These non-inflammable supports absorb appreciable amounts of water which causes alterations in the dimensions of the support. In addition they are mechanically inferior to cellulose nitrate.

The excessive affinity for water of cellulose di-acetate can often be remedied by applying

a thin coat (1-5 μ) of cellulose nitrate or nitroacetate. Cellulose tri-acetate more nearly approaches the nitrate in its mechanical properties but unfortunately it is insoluble in the usual solvents. The difficulties in preparing tri-acetate types of support have, however, been overcome and this material has now replaced nitrate film completely in most countries. For the manufacture of celluloid in thin transparent sheets (H. Goodwin, 1887; H. M. Reichenbach, 1889), collodion, of a consistency approximating to that of honey, is prepared in mixing tanks by dissolving nitro-cellulose and camphor (natural or artificial), in a mixture of methyl alcohol with the addition of another less volatile solvent such as amyl acetate. The highly-viscous collodion is passed through a filter press and on to the coating machines. The evaporation of the more volatile solvent leaves a very concentrated solution in the less volatile one, which results in a homogeneous, non-porous, and transparent film which is actually a solid solution of nitro-cellulose in camphor. The volatile solvents are recovered as they evaporate and are used again.

The first flexible film was coated on to a plate glass table, about 50 ft long, by a moving hopper. The collodion was dried and the emulsion was then coated and dried before the complete film was stripped from the plate glass. Film base, as it is called, is now made by a continuous process. The machine consists of a slowly-revolving large cylindrical drum with a highly-polished nickel surface. A layer of collodion overflows from a trough on to the drum, and is dried by a current of warm air. Before the revolution of the drum is completed the film is stripped off and carried by an endless band to the spooling machine. In some plants the cylindrical drum is replaced by an endless band of polished copper, aluminium, or nickel coated with gelatine.

Whatever be the base employed, it must, before coating with emulsion, be coated on the side which is to receive the emulsion with a substratum designed to secure adherence of the emulsion to the support during the various manipulations. This generally consists of gelatine dissolved in a solvent of the base, e.g. acetic acid. Thus is obtained a transition layer whose composition varies progressively from that of the support to that of the gelatine. On the other hand, too good adhesion may reduce the suppleness of the support and cracks in the emulsion surface may be transmitted to the support.

The coating of a substratum is sometimes replaced by a superficial saponification of the cellulose ester regenerating cellulose to which the emulsion can adhere directly.

For coating the emulsion, the base passes round a large cylindrical drum, cooled internally to allow the gelatine to set; a kind of tank formed by silver rollers, rolling by pressure against the film, is kept full of emulsion, which adheres to the film in a quantity determined by the temperature of the emulsion and the speed of the machine. The film, covered with wet emulsion, is hung in festoons from rods, distributed in a continuous manner on an overhead track, and thus travels a sufficiently long distance in the drying room, which is traversed by a current of warm air. The dry film is wound on to reels containing about 400 ft, and, after examination, is passed to the automatic cutting-up machines.

244. Chemical and Physical Properties of Flexible Supports. Unfortunately cellulose nitrate and acetate are not so inert as glass but are continually changing. Cellulose nitrate (celluloid) constantly releases nitric acid and nitrogen peroxide owing to the presence of traces of adsorbed or combined sulphuric acid. The release of these substances proceeds very slowly in the cold and in darkness, but is accelerated by light, especially by ultra-violet, and heat. The liberated products can, in time, affect the sensitivity of the emulsion and the latent image, the action being more rapid as the humidity of the coating increases. After a time, which varies according to conditions of storage, and which averages about thirty years in temperate climates, celluloid disintegrates into minute fragments. New celluloid ignites almost instantaneously when heated to 170°C, this temperature being appreciably lowered on ageing. Prolonged heating at a lower temperature leads to ignition as the accelerated decomposition leads to a spontaneous increase in temperature. Celluloid may ignite spontaneously when it comes in contact with an electric light bulb or steam pipes. Once ignited, celluloid cannot be extinguished as combustion takes place in the absence of atmospheric oxygen. At the most, in the first few seconds of combustion, one may extinguish it by reducing the temperature by means of large quantities of solid carbon chloride. The gaseous combustion products are rich in nitrogen peroxide which attacks the lungs, and when combustion takes place in a confined space carbon monoxide and a little hydrocyanic acid

may be produced, both of which are highly toxic. Hydrocyanic acid is more abundant in the combustion of supports carrying a gelatine layer than that of uncoated support.

Cellulose acetate supports can be perfectly stable when they are manufactured with all desirable precautions and their durability is certainly equal to that of the best papers. Acetate supports do not burn as easily as paper and combustion ceases when out of contact with a flame. Combustion is without flame and is easily extinguished. The gaseous combustion products contain, as toxic substances, only very small amounts of hydrocyanic acid, in the case of gelatine-coated support. These supports may, however, disintegrate after prolonged storage in a dry atmosphere.

Cellulose nitrate negatives must be stored in the dark in a cool dry place. On the contrary it is recommended that cellulose acetate should be stored at 50 per cent relative humidity; the storage temperature is not critical (B. W. Scribner, 1939).

245. The slow evaporation of the residual solvents and traces of plasticizer causes a progressive shrinkage of flexible supports, at first rapid, then more and more slowly with a maximum shrinkage of 1.5-2 per cent after a considerable time. The gelatine is permeable to the solvents of the support only when wet (I. M. Culham, 1944). When immersed in water or aqueous solutions flexible supports expand, the expansion being, on average, 0.5 per cent for cellulose nitrate and 1 per cent for acetate. After drying, the support has a shrinkage of about 0.5 per cent of the dimensions before wetting. Flexible supports absorb water from a humid atmosphere and give up moisture in a dry one. Under these conditions the expansion of cellulose nitrate is about 0.01 per cent when the humidity of the air is above 1 per cent. In the use of cellulose acetate the expansion is about double. The changes in dimensions are usually less along the roll of support than across it. These variations are usually accompanied by other general and local variations.

The immersion of the support in a solvent for the plasticizer which is not also a solvent for cellulose ester removes some plasticizer from the support and causes shrinkage and warping. Films should not be immersed in a solution containing more than 20 per cent ethyl alcohol.

246. The mechanical properties of films vary considerably with temperature and the amount of absorbed water. They depend also, to a large

extent, on the quality of the cellulose used for manufacture of the support. At low temperatures (below 20°C) frequently encountered at high altitude, the films (in common with other plastic materials) become brittle and break when rolled and unrolled. The flexibility returns on raising the temperature. At temperatures of about 80°C films begin to soften and can be moulded and welded under great pressure. At intermediate temperatures flexible supports can be deformed by tension; their elasticity is extremely poor. After releasing the applied tension they may lose no more than 4 per cent of their elongation. Above a certain degree of elongation the film will yield under great tension and is broken. Cellulose acetate elongates more than nitrate under the same tension and breaks under a lower strain and is less resistant to folding. For these reasons cellulose nitrate was preferred for the manufacture of cinematograph films.

In a high vacuum, as in an electron microscope, the evaporation of residual solvents makes the film very brittle.

A cellulose support dried under uniform tension is very often birefringent; the study of supports between crossed polarizers gives useful information on the tension to which the supports are subjected and some indication of their mechanical properties.

247. The rubbing of a flexible support or its unrolling after spooling yields an electric charge which can give rise to a potential difference of many thousands of volts which will give a spark of about a metre in length. The charges are particularly great when the air is very dry. When the support is in equilibrium with air at 60 per cent humidity, charges of opposite sign which tend to accumulate on the emulsion surface and the back, neutralize each other through the support (V. B. Sease, 1928). In a dry atmosphere the discharge, which is produced causes static markings, often of tree-like appearance, in the emulsion. These markings may appear as dark fog marks on a light background and as desensitized marks on a dark background in the negative (Claydon effect, §209).

It is necessary to protect unbacked films (cinematograph films and films in long rolls for aerial photography) against accidents, by means of an anti-static coating containing a hygroscopic substance on a metallic salt which increases the conductivity of the back of the support and this facilitates the discharge of the electrostatic forces.

248. Cellulose nitrate and di-acetate are soluble in a large number of organic solvents. Solvents suitable for both types of support are ethyl lactate, methylglycol (cellusolve), dioxane, acetone and glacial acetic acid. Amongst solvents for cellulose nitrate only, are methyl alcohol, mixtures of ethyl alcohol and ethyl ether and a larger number of esters, notably the ethyl and amyl acetates. Cellulose di-acetate is soluble in methyl acetate or formate and in methylene chloride. Cellulose tri-acetate dissolves with difficulty in methylene chloride. When these various solvents contain an appreciable amount of water they no longer hold the cellulose esters in solution.

249. Papers. The properties required of papers which are to be used as supports for emulsions vary according to the use to which the paper will be put. Paper negatives may be used for printing by transmitted light, for direct reading, as in the case of self-recording instruments, or for reproduction only by reflected light, e.g. in the primitive cameras used by itinerant photographers and in some semi-automatic "while-you-wait" portrait cabinets introduced in 1928. Attempts have been made to induce amateurs to use negative paper in rolls interchangeable with roll-film, these images being copied by means of an episcopic projector.

Paper for negatives should be homogeneous in structure, to avoid, as far as possible, the structure appearing on the prints made from it; to avoid too long a time being taken in the printing of each print, a thin unloaded paper is chosen, having sufficient mechanical strength, particularly in the large sizes, not to tear under the stress of the weight of the water absorbed by the paper and by the gelatine. When the emulsion is coated directly on to the substance of the paper without any intermediate layer, the material of the paper should be quite free from all impurities capable of affecting the emulsion or the image in the course of development. Metallic dust should be rigidly excluded.

In the second case, the emulsion is separated from the paper "raw base," as it is called, by a semi-opaque coating made by spreading, with brushes, a mixture of pure barium sulphate (*baryta*) suspended in a small quantity of gelatine solution; after drying, the paper is calendered. Papers for mat prints are coated with a layer in which the quantity of gelatine is less than it is in the case of glossy prints, and, further, calendering is omitted.

The protection conferred on paper by the *baryta coating* applies only to development papers; the print-out papers (Chap. XL), which contain an excess of soluble silver salts, are always coated on paper of excellent quality. Certain papers used for positives direct by reversal (as in automatic machines) are rendered water-impermeable with celluloid so as to reduce the penetration of the baths and thus the times of washing. By virtue of this isolation, greater latitude may be exercised in the choice of paper, particularly as the perfect homogeneity demanded of a paper used as a transparency is not of importance; in these circumstances either "single" (thin) or double-weight (card substance) papers are used.

In either case resin sizing must be protected against the action of alkaline baths, used for many operations, by adding a colloid such as gelatine or casein to the substance of the paper.

For the manufacture of papers with transferable sensitive layers (stripping papers), the paper is first coated with a thin layer of a fatty substance or soap insoluble in water, which is covered after drying with a layer of hardened gelatine or collodion (which latter forms the actual support of the image after the paper has been detached), and finally with emulsion. The paper is not stripped until the various treatments (including drying) have been carried out, so as to give to the whole a mechanical resistance sufficient for the successive operations.

To coat the emulsion the paper passes under an ebonite cylinder, adjusted either to a trough containing emulsion kept at a constant level, or to a second cylinder half immersed in the emulsion. It then passes round part of a cooled drum and finally is hung in festoons for drying, in the same manner as that already described for films.

All papers increase in size when wetted and contract during drying, the final dimensions being less than the original. In the case of papers produced on continuous machines the variations are small in the direction of the roll length but quite appreciable across the width.

The expansion on wetting varies from one paper to another but, for the same paper in the dry state an increase in width of 2.5 per cent and 0.5 per cent in length may be obtained. After drying in air the contraction relative to the original dimensions may be 1 per cent on the width and 0.5 per cent in length. When the paper is wetted and dried several times, the above variations occur each time but, within

limits, the dimensions of the dry paper tend to become constant.

250. Negative Paper. Negative paper, which is deserving of notice owing to its comparatively low price compared with that of plates and films, is generally kept for work in large sizes (direct negatives, or negatives made by enlargement). The types of emulsion used for negative papers are very limited and panchromatic emulsions are very rarely coated on paper. For small sizes, the grain of the paper, which always appears to some extent when prints are made by contact, masks some of the finer details of the image. Various means have been suggested for lessening the apparent granular structure of paper negatives. The best of these methods (Delaine, 1925) consists of giving the paper a light flash through the paper base, before or after normal exposure. The correct exposure for flashing must be found by experiment on another sample of the same paper. The irregular veil produced in processing mostly compensates for the variations in transparency of the paper support. Printing and enlarging by episcopic projection can give good results, but the range of tones of the subject that can be differentiated in the final image is then much more limited than in contact printing.

In addition to negative paper proper, and the various stripping negative papers (forming supports for thin films which are stripped from the paper after processing), other papers are prepared for special purposes. These include papers for certain scientific and industrial recording apparatus, and papers for use with the simplified cameras for the copying of documents (in banks, for copying current accounts; in drawing-offices for the duplication of sketches, etc.). These negative copies are obtained "the right way round" by the use of a prism (§ 123) in front of the lens, and, as a rule, are kept as they are. The emulsion of these papers is considerably hardened, so that it can be dried rapidly by heat without risk of melting the gelatine.

251. Relative Merits of Plates and Films. We will consider here only the point of view of the amateur, with particular reference to the novice, leaving to the professional and other users the responsibility for deciding for themselves in each particular case to which type of sensitive material they will give preference.

To amateurs who restrict themselves to photography in good weather, the roll-film offers the advantages of daylight loading and lightness. On the other hand, for those who wish to

improve their work it is a drawback that it is impossible, without almost acrobatic operations, to develop each negative as soon as it is taken. The novice who, during the day, has found two or three subjects worth photographing is always tempted to "finish the spool" by photographing anything in order not to be obliged to postpone the development of his negatives. Roll-film cameras are usually not fitted with any means of focusing the picture on a screen, and so it is at a disadvantage in doing all that is best for an exposure. Also, a long strip of film is much less easily handled than a plate.

It is possible to take advantage of the lightness and convenience of the daylight changing associated with films, by using a film pack with a plate camera, when need arises, and film packs are available, although at present not made by all manufacturers.

On the other hand, plates offer the advantage of ease of individual treatment and of more flexible cameras. Against plates is their weight, and the space occupied for storage.

252. Halation. If an attempt is made to register an isolated luminous point on a photographic plate, or, if a plate is exposed to light under an opaque screen pierced by a small hole, the image of the luminous point will be found to be surrounded by an aureole, which is limited internally by a sharply defined circle, while externally it fades gradually into the background. This aureole is termed a *halo*, and effects of this kind are comprised in the term *halation*. In Fig. 18.1, *a* represents a luminous point registered without halo, and *b* the halo obtained on an ordinary plate having a thickness of 1/16 inch (each part of the illustration is a facsimile of the original negative).

The formation of a halo is illustrated in Fig. 18.2, which represents a magnified section of an emulsion coated on to a transparent support, which we will suppose for the moment to be glass. Owing to the turbidity of the emulsion, each strongly illuminated point of the coating (e.g. the point receiving the image from the lamp), will itself radiate light in all directions. A fraction of the incident light is diffused from the face of the sensitive coating, and is absorbed by the black surfaces of the camera. Those of the rays which are diffused in directions almost parallel to the surface of the emulsion cause *irradiation* (§ 212), i.e. a spreading of the image on to neighbouring portions, which we have seen to be negligible in ordinary photographic work.

The luminous rays diffused towards the back traverse the support and reach the back surface of the latter. Those of them which are least inclined pass through the surface into the air,

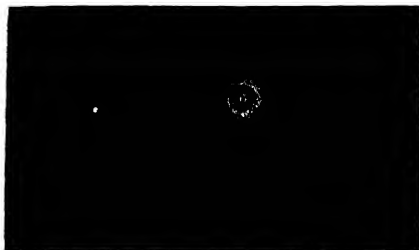


FIG. 18.1. A POINT (a) AND ITS HALO (b) AS OBTAINED ON A GLASS PLATE

and are absorbed by the black surface of the negative holder; the rays that reach the back surface of the glass at an angle equal to or greater than 41° (the limiting angle for glass of mean refractive index 1.5) cannot emerge, and are totally reflected, thus forming the halo round the true image. The diameter of the circle of the halo is, for glass of a refractive index 1.5, 3.58 times the thickness of the glass. The proportion of diffuse light reflected at a plane surface on its passage from air to glass of refractive index 1.5 is about 9 per cent of the incident light. This rises to 60 per cent on the passage of light from glass to air, which means that the total amount of light reflected is a considerable fraction of the incident light.

The dimensions of the halo depend entirely on the thickness of the support and its refractive index. It is practically negligible with thin film as long as the image is not appreciably magnified. The intensity of the halo depends on the turbidity, the thickness, and the colour of the emulsion, as well as on the method of development. A thick or a yellow emulsion gives less halo than a thin or uncoloured one. Finally, the halo increases in relative intensity with increase in exposure.

While halos are less broad on films than on glass plates they form much closer to the illuminated point of the emulsion and with a greater intensity, so that they reduce to a greater degree the resolving power, which is not much influenced by halation in the case of plates.

The halo does not exhibit the geometric form which we have considered, except in the very rare cases in which separate bare lights appear against a dark background, as in the case of the photography of roads in towns at night, where, to obtain detail, there is, perforce, considerable over-exposure of the light-sources. In the case of a highly illuminated surface included in the field, the sum of the individual halos of each point of this surface causes its image to overlap the images of adjoining darker bodies. It is in this way that the image of the window, in the photograph of an interior, is spread out and distorted, the rectangle becoming curved and the image of the cross-bars disappearing more or less completely. In landscape photography the image of the sky shades off into that of the ground and of the trees or buildings which appear in outline against the sky, the slender branches of trees disappearing more or less completely. In the copying of a pen-and-ink drawing or letterpress, the image of

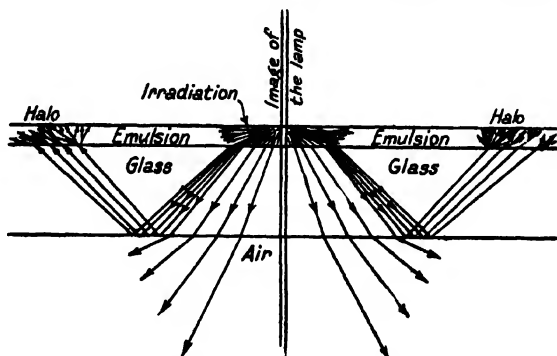


FIG. 18.2. MECHANISM OF HALATION

the white paper encroaches more or less on to the images of the lines, and can, in certain cases, completely obliterate the finer details. The mistake is sometimes made of attributing to halation (defined as above) the effect caused by dirty lenses, particularly in the absence of an effective hood, and, in the case of isolated luminous points, the diffraction effects due to the iris diaphragm; in the latter case the image resembles a star with as many rays as the diaphragm has leaves (or double this number if it is odd).

Halation seems reduced by very short development, but no addition to the developer can avoid or eliminate halation except for some small

improvements by surface-acting developers (§ 253). It is clear that a developer cannot behave differently towards parts of the plate that have received, after the light has travelled by different paths, equal excitations.

Even when the halo does not show as an alteration of the shape of the image, it appears as a veil, which is in addition to the veil due to reflection of light in the lenses (§ 58).

253. Prevention of Halation. Halation can be prevented or diminished by using an absorbing layer between the sensitive emulsion and the support (anti-halo undercoat) or on the back of the support (anti-halo backing).

To be completely efficient the anti-halo layer should totally absorb all the radiations to which the emulsion is sensitive. Generally, particularly with films, only a portion of the active radiation is absorbed. The halation produced on panchromatic emulsions by red light is often more dense than that formed by blue light as the red light is less absorbed by the sensitive layer. Panchromatic emulsions being more generally used with a yellow filter or in artificial light rich in red radiation, have an anti-halo layer which is sometimes coloured blue or green. In practice an anti-halo layer should comply with the following conditions: (i) the colouring matter or pigment used must have no effect on the sensitive emulsion when it is in contact with it, (ii) it must be completely eliminated during the course of processing without inconveniently colouring the solutions used, (iii) the anti-halo layer should not be very thick, especially on films for small negatives, and (iv) it must not absorb during processing an appreciable quantity of water which would retard washing and drying.

Some means of diminishing halation, which have a limited effect, consist of increasing the absorption of light by the sensitive layer by incorporating in the emulsion a yellow dye (which appreciably reduces its sensitivity) or by using a matting agent, or coating the emulsion very thickly. When the incident light strikes the surface of the emulsion layer, irradiation predominates in the surface and halation in the depths of the emulsion layer. A developer which has surface action tends to reduce halation which, on the contrary, would be increased by a more active developer which penetrates into the emulsion layer.

The first known method of prevention of halation was the application to the back of the glass of an absorbent layer (Marlow, 1861), in

optical contact with the support, having a refractive index at least as great as that of the glass (Carey-Lea, 1865; Cornu, 1890).

A later method was the interposition of a light-absorbent coating between the emulsion and the support. This material may be either an opaque salt or a dye. It is eliminated during the course of development or fixation, or by special treatment. A disadvantage common to all anti-halation substrata is the increase in the total thickness of the gelatine which retards exchanges within the gelatine in the course of the various treatments and washing and also retards drying.

With some panchromatic films with a bluish or greenish anti-halation layer decolorized by the alkali of the developer, the use of an excessively acid fixing bath or any subsequent treatment in an acid bath may cause the re-appearance, uniformly or in irregular patches, of the original colour. This may be removed again by an alkaline bath (5 per cent solution of sodium carbonate); the effect of an ammoniacal bath does not always persist after the ammonia has evaporated.

In the case of plates the anti-halation coating is occasionally in the form of a layer intermediate between the glass support and the emulsion, for a coat on the back runs the risk of being scratched when the plates are placed in the sheaths or dark-slides. In films it is generally combined with the coating that most films have on the back, this coat being sometimes covered with a very thin coating of wax to facilitate sliding.

For ciné film, use is sometimes made of a support permanently tinted a grey of such intensity that, crossed twice under a very oblique incidence, it reduces halation sufficiently without slowing down printing excessively, as it is then crossed once only by the light and that under an incidence very close to the normal.

254. Expression of the Speed of Negative Materials. The speeds of the first gelatine-bromide plates were only expressed by different names. Unfortunately, the plates called "extra-rapid" in 1880 (by comparison with the collodion plates used until then), and which are now considered as slow plates, have kept their old name and all the superlatives have been used until they have lost their meaning regarding speed of the photographic emulsion.

It would appear impossible to represent, by one number, the speed of a sensitive negative

material, which is only described very incompletely by the characteristic curve (§ 203), especially as the speed is not, as most photographers openly admit, the only property of a sensitized material, and often not its most important one. However, the increasing use of exposure meters renders it very desirable that some dependable indication of the speed of emulsions under their normal working conditions, should be given. Speed values, obtained by various methods, are usually given with roll-films, but unfortunately these speeds are more usually determined by the publicity service than the technical service. Thus it sometimes happens that films of the same speed, supplied at intervals from the same maker, are given successively increasing speeds, and it is wise not to place much faith in these figures.

The optimum exposure for obtaining a negative being based on the correct rendering of the shadows (Chapter XXVI), the speed should be determined by a conventional criterion (the light corresponding to a certain density, or a certain slope on the characteristic curve, after development under standard conditions) in the region where a density is just formed. For a reversal or positive emulsion the criterion should be chosen in the neighbourhood of the maximum black.

255. Hurter and Driffeld Speeds. The first reasonable method for the determination of the speeds of plates was put forward in 1890 by F. Hurter and V. C. Driffeld (H. and D. Method). The plate is exposed at 1 m from a lamp of one candle-power, with a series of nine exposure times from 0.156 to 40 sec, given by the rapid rotation of a shutter disc with suitable apertures. After development such that the gamma is equal to 1, the densities are measured and the characteristic curve drawn (§ 203). The *inertia* of the material under test is then defined by the point at which the exposure axis is cut by extending the straight line portion of the curve; the speed is then obtained by dividing the number 34, chosen arbitrarily, by the inertia expressed in metre-candle-seconds. If the candle is replaced by a source approximately equivalent to daylight (e.g. an acetylene flame or electric lamp, with a blue filter) the increased actinic value of the light can be compensated by replacing the number 34 by 10, the same results being then obtained for non-colour-sensitive emulsions.

At the time at which this method was proposed, the characteristic curves of different

types of emulsion differed only by their displacement parallel to the exposure axis, and thus to measure this displacement was enough to define their relative speeds. The varied shapes of modern characteristic curves and the frequent use of emulsions of which the curve has a long region of slight curvature, on which most of the densities of a negative would fall, has removed all practical meaning from the H and D speed.

256. Scheiner Speeds. In the Scheiner method (1894) the least exposure is determined, which, after development under standard conditions in a ferrous oxalate developer, gives a density which can just be distinguished from the fog. This system was a natural result of Scheiner's being an astronomer, and gives the material a speed corresponding to its use for stellar photography. In order to do this, the plates were exposed, at 1 m from a lamp burning a standard mineral oil, behind a disc shutter giving 23 exposure times from 0.013 to 2.614 sec. After development the number of the last visible step was taken as the speed criterion. It is, approximately, ten times the logarithm of the reciprocal of the exposure corresponding to the threshold. The method outlined above, not being readily applicable in practice (particularly to colour-sensitive emulsions), each laboratory using the "Scheiner method" uses, in fact, a different variation of the original method; the results obtained by different laboratories are thus rarely comparable.

257. DIN Speeds. As a result of the work of the German Standards Association a method has been adopted in that country which is named, from the initials of the German name of this organization, the DIN method (*Deutsche Industrie Normen*). The sensitive material is given an exposure of 1/20 sec behind a sensitometric wedge having 30 steps differing in density by 0.1. The wedge receives illumination of 40 metre-candles from an incandescent lamp, through a blue filter giving, in the visible region of the spectrum, an energy distribution very close to that of average sunlight (R. Davies and K. S. Gibson, 1928). The development of the image, in metol-hydroquinone developer, is carried out such that the emulsion under test has the highest possible speed. The step is then found on which the density just exceeds 0.1 above fog: the speed is expressed as a fraction in which the denominator is 10 and the numerator is then determined from this step, being ten times the density of the corresponding step on

the wedge. The fraction thus gives the speed on a logarithmic scale.

This method provoked much criticism in the United States, France, and Great Britain, based almost solely on the abnormal development conditions, which are such that there is no definite relationship between the speed thus determined and the practical speed. Several treatments, carried out in the course of manufacture for this purpose, can increase the optimum speed without increasing the practical speed in the same proportion. For instance, a method of increasing speed by immersion in warm mercury, described by U. Schmieschek (1940) increases the threshold speed of a slow film 33 times, while the practical speed is only increased 4 times.

A war standard, published in 1941 by the British Standards Institution, adopted as a speed index the amount of light E giving, after development under standard conditions, a density of 0.1 above fog. The development conditions are equivalent to those normally used in the development of negatives. The light source is the same as in the German method and the different exposures can be made with either variable illumination or exposure time, the only condition being that the exposure giving a density of 0.1 above fog should be between $1/20$ and $1/40$ sec, or that the density of 0.1 should fall between the densities of steps exposed for $1/20$ and $1/40$ sec. The speed is then expressed as the whole number closest to $-10 \log E$.

258. Practical Speeds. It can be seen that adequate correlation, let alone equivalence, cannot be expected between results obtained by methods which measure different characteristics of the emulsion, rather than the practical speed.

An essentially practical method in use, mainly in the United States, is the Weston speed. It is defined as 4 times the reciprocal of the exposure required to give a density numerically equal to the gamma obtained in development. This method is said to have received thorough practical tests, and speed figures are published by the makers of the Weston meter on the basis of regular practical tests on all materials on the market. Before the introduction of the ASA system described below, the Weston system was regarded as the most reliable.

A method due to L. A. Jones (1939) allows the practical speed to be determined. The method has been established after a great deal of preliminary work during which the same sub-

ject, illuminated by constant conditions, has been photographed many times with exposures suitably graded such that some negatives were under-exposed and others over-exposed. From each negative best possible prints were made on different grades of paper. These prints were then examined by a very large number of observers, and from their assessments it was

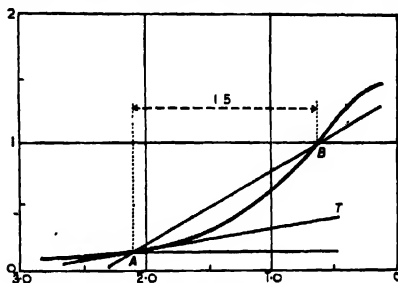


FIG. 18.3. MINIMUM USEFUL GRADIENT
METHOD OF SPEED ESTIMATION
(L. A. Jones.)

possible to determine, for each of the subjects, the least exposure which could give a print of excellent quality.

This having been done, it was then necessary to establish a sensitometric method, which would be easily applicable to testing in a control laboratory, and which would give results in agreement with the statistical method outlined above. This method, used in practice now for several years by an American manufacturer of photographic materials, is as follows. The characteristic curve of the material is drawn for conditions corresponding to normal exposure and development (Fig. 18.3). Two points A and B, separated by a distance of 1.5 log units on the exposure axis (ratio of extreme brightnesses of $32:1$), are moved about so as to find a position such that the slope of the tangent AT at the point A should be equal to 0.3 times the slope of the line AB. The speed is expressed as the reciprocal of the exposure (in metre-candle-seconds) received at A.

Separate verifications have established the excellent agreement between the numerical values thus obtained and the practical speed of sensitive materials used under their normal conditions.

These experiments have shown, incidentally, that excellent photographs can be obtained by taking negatives in which all the densities are situated in the region of the characteristic curve

normally designated as under-exposure, and even at points where the slope is as low as 0.05. Details of tone completely invisible on the negative appear on the print, due to the use of a very contrasty paper.

This method has been adopted by the American Standards Association (1943) and more recently (1947) by the British Standards Institution. Calling E the exposure corresponding to the point A , the "ASA" speed is expressed by I/E , being preceded by a zero and rounded off to the nearest value of the geometric progression having the cube root of two as its common ratio (i.e. 0800, 0640, 0500, 0400, 0320 . . .). For use with the tables or calculators of exposure meters, a speed index known as the "American Speed Number" is used, being $1/4$ of the ASA speed, and not preceded by a zero. For example, the ASA speed of 0200 corresponds to a speed index of 50.

The British Standards Institution in 1947 introduced a speed-rating system which is similar at all speeds to that recommended by the ASA, and an emulsion which has a rating of ASA 100 will also have a rating of B.S.I. 100. In addition to the above-mentioned systems which are called arithmetical, since a doubling of the index indicates a doubling of the speed, both the B.S.I. and ASA ratings can be given in logarithmic units. $28^\circ \log$ is equivalent to 50 arith, and an increase of 3° indicates a doubling of speed. The arithmetical system seems to be favoured in America, the logarithmic system in Great Britain.

259. Properties of Negative Emulsion Layers. Besides the speed, which has already been stated as being only one of the essential properties of a plate or film, the photographer, in his choice of material, has also to take account of the following considerations.

For photographing coloured objects the property of first importance is obviously a wide range of colour sensitivity so that the factors of the colour filters used are not too high. For photography in artificial light exposures can often be shorter on panchromatic emulsion than on orthochromatic which is faster to daylight.

When the negatives are to be greatly enlarged the graininess becomes of importance, and although it is possible to use a very fast coarse-grained emulsion and a greatly shortened development time, the effective speed is reduced to a fraction of its normal value. It is better to use a slower fine-grain emulsion, developing it normally and using its full speed.

As large an exposure range as possible is an essential property for photography of very contrasty subjects (i.e. subjects having a large brightness range). This property is also valuable to the beginner in photography, and even for the experienced photographer called upon to work under conditions very different from those under which he normally works. For example, if the material allows an exposure range in which the ratio of extreme illuminations is 2,400, there is a large exposure tolerance for a subject in which the brightness range is 30, the ratio of the extreme exposure times which would give negatives inside the scale of the exposure range being $2,400/30 = 80$, which makes it almost an impossibility to obtain a useless negative.

For reproducing documents or objects which have a very small brightness range, the maximum contrast (γ_∞) of the emulsion is an essential property, and it is an advantage if development is continued as long as possible, without the appearance of general fog, to obtain this maximum contrast. Good keeping properties of a sensitized material, without loss of speed or appearance of general fog, is an indispensable quality, particularly for plates or films which are only used occasionally. Perfect latent-image stability is necessary whenever considerable time is to elapse before development.

The emulsion should be sufficiently hardened to avoid excessive swelling during processing, very swollen gelatine being extremely delicate and liable to cause several troubles (stripping, reticulation, etc.). This property is particularly important at high temperatures, and some makers therefore supply special materials for tropical use. It is advantageous that the emulsion should not continue to harden after the material has been supplied to the user which would necessitate the use of longer and longer development times.

Lastly, it is an advantage, in all emulsions other than those intended for copying documents composed only of black and white, that the variation in gamma with development should be slow in the region of the optimum value, thus reducing the effects of error in development time or developer temperature.

If some of the makers of sensitized materials were to publish reasonably complete data, in the form of graphs or tables of numerical values of the majority of the above characteristics (average values, of course, and not values determined for one particular batch of emulsion), it would then become necessary for such a

policy to become general. Such data are only of interest, however, when the characteristics described are reasonably constant from one batch to another.

260. The Different Types of Negative Materials.

As an example of the complex structure of some modern sensitized materials, it is interesting to note that one negative film for cinematography, of German make, is made up of an anti-static

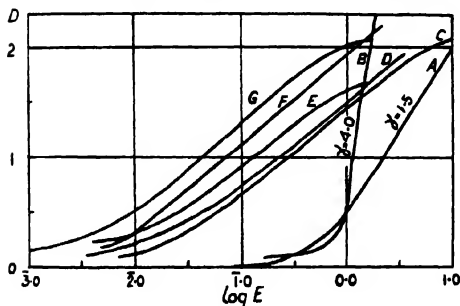


FIG. 18.4

backing, the support, a blue-grey anti-halo undercoat (which is not bleached in processing), the "subbing" coat, two layers of emulsion, and lastly an anti-abrasion coating of clear gelatine.

In Fig. 18.4 are shown the characteristic curves of some emulsions of the same make (all drawn for $\gamma = 0.8$ unless otherwise stated). The following table gives the corresponding information.

	Jones Speed	Maximum Reading	
	Daylight	Tungsten	gamma
			(γ_{∞})
			Resolving power (lines/mm)
A. Positive Cinematograph film	—	—	1
B. Blue-sensitive Process emulsion	—	—	5
C. Panchromatic negative Cinematograph film	—	—	1.4
D. Rapid ortho roll film	160	80	1.5
E. Very fine grain panchromatic film	135	80	2
F. Rapid ortho portrait film	—	—	0.9
G. Ultra-rapid panchromatic film	640	300	1.8

It will be seen that for the old-type emulsion (F) the straight-line portion of the characteristic curve is very long, that it is noticeably shorter for the modern negative emulsions and is reduced to a very short length for the fine-grain emulsion (E).

Although it is impossible to obtain directly a high value of gamma on a rapid emulsion, it is possible, on the emulsions especially prepared for high contrast (A and B), to obtain low-contrast

negatives by reducing the development time or diluting the developer. A satisfactory negative of a subject covering a wide brightness range cannot be obtained on such a material, however, as a high contrast emulsion will only cover a narrow exposure range.

Assuming the general use of exposure meters which allow the use of emulsions with a small exposure tolerance, several makers of roll-films (especially in Germany), considered about 1938, that the thickness of the layer of emulsion (normally 10μ for single-coated films and 12 to 15μ for double-coated films) could be reduced to about 8μ , and the weight of silver bromide (usually 13 to 18 g/m^2) to about 4 g/m^2 . The characteristic curve of such film has no straight-line part, and the exposure range is very small.

To extend the exposure range, and thus the exposure tolerance to the maximum, it has already been stated that a rapid emulsion can be coated on top of a slow one. The rapid emulsion should be completely exposed by an exposure only slightly greater than that corresponding to the threshold of the lower emulsion in order to avoid excessive densities. The diagram (Fig. 18.5) shows, in the case of two perfectly balanced emulsions, the rôle of the slow

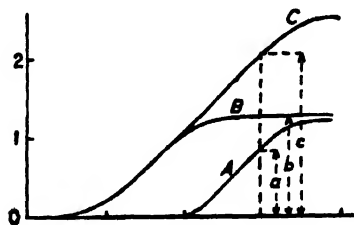


FIG. 18.5

emulsion A which gives, in place of the curve B of the rapid emulsion, the curve C, which is such that the ordinate C is, at every point, equal to the sum of the ordinates a and b of the subsidiary curves.

261. Ageing Properties of Sensitive Materials.

The speed and maximum contrast of a sensitive material change as it ages, at first very rapidly and then more and more slowly, if the material is kept at constant temperature and humidity. For example, on a negative film kept at 21°C in an atmosphere of 50 per cent relative humidity, the following observations were made (M. E. Russell and L. A. Jones, 1937). After 20 weeks the properties had become stabilized.

After periods considerably longer than those considered here, a general fog appears, giving a density which increases with the age of the material and with humidity. On plates severe fog may form along the edges which limited the coating of the emulsion, but not along edges cut after drying. This appears to be due to migration during drying, from the edge towards the centre, of the potassium bromide added to improve keeping (B. Homolka, 1905), it is not apparent on roll-films, in which the edges of coating are always removed before slitting.

In a very dry space (cathode-ray oscilloscopes, electron microscopes, etc.) the gelatine tends to lose moisture, and the resultant contraction of a relatively thin layer of emulsion sometimes causes fog by a process comparable to that of abrasion (see also § 200).

	AGE OF FILM			
	0	10 days	6 weeks	20 weeks
Relative speed	24	22	20	19
Maximum gamma	2.20	—	2.04	2.02

262. Increase of Speed of Negative Sensitive Materials. Many conditions tending to produce a general fog give, before the actual appearance of fog, or before it has acquired any considerable density, an increase in the threshold speed or reinforcement of a latent image already present. The increase of the practical speed is considerably less, so that procedures for further sensitization are only of interest when the important details are to be recorded by exposures close to those which would give a density only slightly above that of the fog.

Increase in speed by a uniform extra exposure (the easiest to regulate) has been studied several times, with results often contradictory and necessitating the use of prime operating conditions. The experiments of C. E. Weinland (1928), J. H. Webb and C. H. Evans (1938), and P. C. Burton and W. F. Berg (1943) have given the following facts. If an under-exposed image is recorded in intense light, the latent image specks are too small to respond to development; a uniform exposure to very weak light can increase their size to the critical value for development without producing new specks, and thus without increasing the fog. This process is now commonly described as "latent-image intensification" or "latensification." On

the other hand, on many emulsions, a very small uniform exposure made to high intensity allows an under-exposed image produced by light of low intensity to be recorded successfully. Here the first exposure "hypersensitizes" the material towards the second; the preliminary uniform exposure gives latent image specks too small for development, but, by further exposure, these increase in size to that necessary for development.

The experiments of G. S. Moore (1941), undertaken under V. B. Sease, have shown that a latent image formed in 1/30 sec on a fast emulsion, panchromatic or otherwise, is reinforced in a very noticeable manner by a uniform exposure of long duration at a very low intensity, controlled so that the fog produced does not exceed 0.2 after 30 to 60 min. The effect is equivalent to a speed increase of 2 to 4 times depending on the emulsion and development. It is independent of the colour of light used for the extra exposure, and is a maximum for auxiliary exposure times of the order of 30 min. The contrast of the image is always lowered, but to a lesser degree as the auxiliary exposure time is increased almost regaining its initial value after 2 hours. A similar extra exposure given before the main exposure to a high intensity has little useful effect and may even lower the speed slightly without reducing the contrast. The reinforcement of the latent image is practically the same whether the extra exposure is given from the back or front of the emulsion (even in the case of double-coated films), but the loss of contrast is less when it is given from the back.

Similar effects have been obtained by immersion of materials in very dilute solutions of hydrogen peroxide, or of various other fogging agents.

On certain emulsions the practical speed can be increased by exposing the plates or films for about 36 hours in an atmosphere saturated with mercury vapour at the ambient temperature (H. Baukloh, 1928; Dersch and Duerr, 1937). The effectiveness of the treatment depends essentially on the relative humidity, and is a maximum in an atmosphere of 50 per cent relative humidity. In a very moist atmosphere the sensitivity is lowered and the fog increased. The useful effect is greatest when the treatment is carried out after exposure, and lasts about 15 days (A. Rondia and E. Vassey, 1943). Speed increase has also been observed after immersion for a few seconds in mercury at about 100°C (U. Schmieschele, 1940). *It should be noted that the vapour given off freely by warm mercury is extremely poisonous.*

CHAPTER XIX

DARKROOM ILLUMINATION

263. General Principles. The choice of illumination to be used when handling sensitive material, either during manufacture or during the various operations prior to and including fixation, depends on two factors, firstly on the distribution of the spectral sensitivity of the emulsion under consideration, and secondly on the colour sensitivity of the eye.

It may be laid down that there is no really *non-actinic illumination* in the true sense of the word; that is to say, that there is no light, whatever may be its spectral distribution and however weak in intensity it may be, which will not fog a photographic emulsion if allowed to act for long enough.

It is seen that in choosing suitable illumination for a darkroom a compromise has to be made between somewhat incompatible conditions. Sufficient light must be available, when needed, for the effective control of operations being carried out, but this must not appreciably fog the sensitive material during the normal time required for the necessary manipulations.

In order to make the practical application of these ideas clear, the optimum conditions for handling a panchromatic emulsion equally sensitive to all the colours of the spectrum will be considered. Three filters, coloured respectively blue-violet, green, and red, each transmitting a third of the range of the visible spectrum and in the same proportions, could be used indifferently as filters for the darkroom lamp if only the actinic values of the light thus transmitted were being considered. An emulsion, given the same exposure time, would give the same fog-density to each of the three illuminants. But, if the physiological response to the three illuminations is considered, the blue-violet becomes a poor illuminator, the red little better, while the best visibility is obtained by the use of the green. This is in agreement with what has already been stated with regard to the spectral sensitivity of the human eye (§ 4, Fig. 1.2). If, by suitable regulation of their respective intensities, two filters, coloured red and green, were prepared to have the same visual intensity, it will be found that if the source of light common to both be reduced in intensity, the red will appear less intensely

illuminated than the green (Purkinje phenomenon).

By means of the aperture of the iris and the sensitivity of the retina, the eye adapts itself automatically to low levels of illumination after a period of time. While the opening and shutting of the iris is very rapid, the adjustment of the retina is slow. From bright sunlight to darkness about half an hour is required for adaptation while approximately ten minutes is necessary when passing from normal illumination to that of the photographic darkroom. The rate of adaptation from light to dark is very much slower than the reverse action. When coming into the light for a short time, after dark adaptation, in order to avoid the loss of time of a fresh adaptation, black spectacles (density 2, approximately) with a fitting excluding all light except that passing the glasses may be worn. The presence in the field of view of a spot more strongly illuminated than the objects that are being looked at reduces the sensitivity of the eye and is a cause of fatigue. This is found in its worst form if the lamp, or its reflection from some bright object, is in the field of view when the illumination in the darkroom is extremely low (P. G. Nutting, 1916).

The same physiological considerations still apply even when the emulsion under consideration is not equally sensitive to the whole of the spectrum. For example, an emulsion sensitized with pinachrome may be regarded as insensitive to the extreme red (beyond $680\text{ m}\mu$) but a coloured filter transmitting only these radiations would appear so feebly luminous that a green filter, transmitting much less luminous energy but giving the same visibility, would give, as a rule, an equal degree of safety. For the same reason, although an orange filter usually transmits all the red, there is often less risk of fog with an orange light than with a red one, since, for the same visibility, less total luminous energy is necessary. The advantage of an orange light is particularly noticeable when working with very rapid emulsions which, as we have seen, are often slightly sensitive to the extreme red (§ 223), as the proportion of these feebly active radiations is much less than it would be in the case of a red light.

The source of light and filter combined must not transmit ultra-violet which is very active on all sensitive emulsions. (This condition is satisfied when the usual artificial illuminants are used, but it must be borne in mind if daylight is employed or electric lamps with metallic gases or vapours of neon, mercury, sodium, thallium, etc.).

264. Choice of Darkroom Illumination. In practice, the following lighting is used for various types of sensitive material—

Slow positive silver chloride emulsions (for development)	Yellow
Rapid positive silver bromide emulsions	Yellow or Orange
Rapid negative emulsions, (blue sensitive)	Orange-red or yellow-green
Orthochromatic emulsions, (green sensitive)	Ruby-red
Panchromatic emulsions	Bluish-green of low intensity
Emulsions sensitive to infra-red, but not to green	Pure green

It should be remembered that red light increases the apparent contrast of images and induces one to curtail the development; where there is a choice of illumination, orange or green should be chosen.

From the fact that a certain red and a certain green are complementary, inventors have attempted to get a colourless non-actinic light for ordinary plates by blending red and green lights, which separately are non-actinic. As it is possible to produce only a yellow in this manner, it is much simpler to use a plain yellow filter in all cases where the sensitivity of the emulsion permits.

Special filters for the illumination of photographic darkrooms are usually described as safelight screens. The safelight screen is generally made by coating a gelatine layer, containing suitable dyes, on glass. One or more of these elements (together with some form of diffuser) may be combined to make the safelight. When photographic emulsions had only a low and restricted sensitivity to intensity and colour of light, commercial coloured glass (manufactured for signals, etc.) was used for safelight filters or screens. With the improved sensitivity of emulsions this type of glass is useless as, although it may have predominantly the required colour to the eye, it probably also transmits in other parts of the spectrum.

Safelights applicable to each case are worked out by taking into consideration the colour sensitivity of the eye and the particular photographic material, and then suitable tests are made to determine the density required for the filter. This may be determined by the time taken to give a certain fog density on the material, the intensity of the light source and distance of safelight from the photographic material being fixed. The minimum safety time is chosen and the density of the safelight screen adjusted to give this safety factor. A darkroom may be well illuminated in its entirety by use of suitable direct and indirect safelights, without the sensitive material being too strongly illuminated. Whereas in earlier times when the traditional deep-red glass safelights were used, only a small area immediately next to the safelight was illuminated and the rest of the room was completely dark.

Although badly illuminated darkrooms hinder work, it is interesting to note that, as a result of many clinical observations on workers in photographic plate and film factories who have worked for many years in darkness or in feebly actinic light, Drs. F. Heim and E. Aglasse-Lafont (1912) have concluded that *occupational anaemia*, caused by working in darkness, *does not exist*.

To ensure good general illumination of the darkroom, the walls and ceiling should be light in colour; the diffused light from the walls cannot be more dangerous than the light which issues directly from the darkroom lamp. Since red light is so frequently used, red ink and pencils which give marks totally illegible in red and faintly legible in yellow light, should not be used for labels, notes, or for any memoranda used in darkrooms.

The use of a desensitizer, either as a preliminary bath or in the developer itself, allows a very bright light to be used from the moment the emulsion has been effectively desensitized, so that the remaining operations may be carried out in a yellow or white light without the slightest risk of fog whatever the original sensitivity of the materials in use.

265. Light Sources. Safelight screens supplied by a reliable photographic manufacturer are recommended for use with a particular wattage lamp, usually a 15- or 25-watt lamp, and provided the lamp is run at the correct voltage, it should be possible to obtain the maximum illumination permissible with any particular emulsion.

Failure in the domestic electricity supply may be guarded against by having an emergency lighting outfit, thus avoiding being interrupted in the course of work. Also an electric pocket lamp may be converted into a darkroom lamp by fixing a safelight in front of the lens, which acts as a condenser for the light.

Particular care should be taken in a darkroom to ensure that all electrical fittings are sufficiently insulated and guarded. Fatal accidents have happened following contact of wet fingers with poorly insulated connexions and earthed fittings, especially when the floor is damp or the other hand is dipped in a liquid connected to earth.

Despite the considerable progress which has been made in electric lighting, most of the energy consumed is converted into heat, and so the ventilation of electric lamps is just as necessary as it is for other types of lamp. The life of an electric lamp is always shortened if the lamp is used at a higher temperature than would be attained if it were not enclosed.

Neon pilot lamps which emit a very feeble orange glow (about 1 candle-power) may be used with advantage where only a very faint light is required (e.g. for reading a darkroom watch or clock placed on the work bench, or for illuminating passages between several darkrooms). Whenever these lamps are used on the work bench a yellow safelight should be employed to cut off the small proportion of violet rays emitted.

The reader should be cautioned against the use of lamps with red bulbs (red glass or glass covered with red varnish), which are more useful for decorative lighting at fêtes than for photographic purposes. The few lamps specially manufactured to transmit the correct part of the spectrum are very much higher priced than ordinary lamps, and the difference in price, after several replacements, amounts to more than the cost of a good darkroom safelight fitting.

266. Safelight Fittings. The chief quality demanded of a safelight is that it shall stop all light other than that which passes through the safelight screen or filter. It must be sufficiently well ventilated not to cause damage through over-heating of the filters of paper or gelatine (charring, melting, etc.), which are obviously more susceptible to injury of this kind than the coloured glass which, at one time, was the only material used. In some safelights the screens are separated from the lamp itself by a sheet of

glass, and the two compartments thus formed are separately ventilated.

From every point of view work is considerably facilitated if the lamp gives only a diffused light. This may be achieved either by the safelight screen itself being a diffuser, or by arranging the source of light so that the light which falls on the screen comes from the mat-white surface of the interior of the safelight box which can be regarded as a source of diffused light. In addition to the safelight which illuminates the work bench, it is useful to have one illuminating the ceiling. This gives a general indirect illumination, the value of which has already been emphasized for other purposes. The screens for this safelight may pass more light than those for bench use. This method of illumination is the only one used in the emulsion-coating rooms of some factories.

It is preferable that the luminous surface of the safelight should not be visible to the operator in his normal working position. This may be achieved by careful positioning of the safelights or by using a hinged shutter or opaque screen to eliminate illumination falling directly into the operator's eyes but which can be removed when required to allow a negative to be examined by transmitted light in the course of its development.

Mention may be made for the sake of reference of an arrangement which has often been commended, namely a plate of glass, illuminated from beneath, on which a glass developing dish is placed. The negative can then be examined by transmitted light when necessary, without it being necessary to remove it from the dish.

It is not necessary to describe the innumerable types of safelight, more or less satisfactory in design and construction, which have been manufactured; description of those at present available will be found in the dealers' catalogues.

267. Testing of Safelights. The spectroscopic examination of safelights, which is sometimes recommended and possibly used as a guarantee of these goods, is entirely illusory. The harmful rays, for example the violet rays transmitted by many red glasses, when dispersed by the spectroscope, affect our eyes so little that they are often unnoticed even when the source of light is the sun or a strong electric arc. A spectrographic examination can only be of use when the eye is replaced by a photographic plate of the same kind as that for which the safelight is intended. It has been suggested (H. Arens and J. Eggert, 1929) that the spectrograph should be illuminated through a filter to

give an equal visual intensity throughout the spectrum obtained. A spectrogram on the emulsion to be used indicates by its least dense areas at what wavelengths the safelight may be designed to give the maximum transmission. A second test with the safelight under test interposed indicates whether the active spectral areas have been absorbed. The only visual examination capable of giving any safe indication as to the quality of a safelight is that in which various filters transmitting only one portion of the spectrum (*monochromatic filters*) are superposed on to the safelight to be examined; in these circumstances the combination should in no case appear to transmit rays which should be absorbed by the safelight.

The best, and, incidentally, the simplest, method of testing a safelight is to make a practical test under reasonable conditions. Taking into consideration a number of factors, such as the time normally required for loading the photographic material into a dark-slide, length of time for development and whether the plate or film will be covered or exposed to the safelight during the development, a period of time is chosen to be the maximum that the material will be exposed to the safelight. During this time it should not receive an exposure sufficient to give any sign of fog on development. Supposing 4 minutes is decided to be the required safety time. Then, to make the test, a plate (or film) is placed in a printing frame, and about a third of it is covered with black paper. A piece of cardboard, which at the start covers the whole of the sensitive surface, is moved back after fixed periods of time, so that successive-strips of the material are exposed to the light; for example these strips may receive

exposures of 1, 2, 4, 8, etc. minutes respectively. After development, the plate is examined, and if the 4-minute strip and the portion which has not been exposed at all do not appear to differ in density, then the safelight may be regarded as suitable for the material in question. If on the other hand, fog appears on the 1- or 2-minute strip, it is necessary either to use a lamp of lower intensity or to decrease the transmission of the safelight: this might be done by adding one or more sheets of paper, or some similar diffusing material. If, however, the first appearance of fog on the test strips indicates that a much longer exposure than 4 minutes is safe, then it is possible to increase the intensity of the lamp. In either case a test should be made after the alteration considered to be necessary has been carried out.

Recent work (§ 262) has shown that an exposed piece of photographic material is much more sensitive to the light from darkroom lamps than unexposed material. The reason is the existence of a non-developable kind of latent image (the sub-image), which is strongly intensified by the weak light emitted from a darkroom lamp. This has the effect of raising preferentially the low densities in the negative, i.e. of lowering the contrast. In the case of negatives for direct inspection, such as radiographs, or in prints, this effect may lead to a considerable deterioration in quality. Thus it is often important to test a safelight with an exposed piece of photographic material; the best method is to print on the material a step wedge or perhaps an ordinary picture, and to expose one-half of it to the safelight. The two halves are then processed together and a comparison will reveal the effect of the safelight.

CHAPTER XX

EQUIPMENT OF THE DARKROOM

268. The Amateur's Darkroom. A specially equipped darkroom is not essential for the production of good photographs. Any room (preferably kitchen or bathroom containing a sink and running water) may be used *after dark* as a photographic "darkroom" without alteration. Care must, of course, be taken to avoid staining the floor, furniture, and wall hangings. They may be protected by linoleum, oil cloth, or American cloth. Work may also be done in a large dish, fitted to serve the purpose of a sink. If the room faces a lighted window or if there is a light outside (e.g. a street lamp), some dark fabric must be hung so that it fits tightly over the window; any light that filters through the cracks will not matter as long as the sensitive films are not exposed directly to it.

The amateur who has sufficient leisure and opportunity to work during the daytime requires a safelight and can fit up, according to his resources, a darkroom similar to that of a professional photographer. Directions are given for this in §§ 269-275.

269. Construction of the Ideal Professional Darkroom. The first consideration is the health and safety of the worker. Do not let the darkroom be so large as to lead to its subsequent conversion into a lumber-room. On the other hand, no room should be smaller than about 6 feet square, with adequate height; 400 cubic feet is usually the minimum space allowed for each worker in a darkroom. In France, an order published in the *Journal Officiel* of 12th July, 1913, to which there have been other references, prescribes: The volume of air shall be at least 10 cubic metres per person employed in a darkroom. The closed rooms used for work are to be well ventilated and comfortably heated in winter. During intervals of work the air in the rooms is to be completely renewed. The floor is to be cleaned at least once a day either *before* or *after* work by washing with a damp cloth. The walls and ceiling are to be frequently cleaned.

Most solutions of salts, particularly the concentrated solutions of hypo used for fixing, cause disintegration of cement. The floor of the darkroom, at least in the working space, should preferably be paved (earthenware tiles, *not*

cement, jointed with bitumen), asphalted, or covered with some impermeable composition. When asphalt and some composition floorings are used, heavy objects resting on the material indent it. Benches and supports for sinks, etc., should therefore be bedded on the floor below. If the floor is of wood, it should be entirely covered with rubber sheeting, rubber tiles bedded in mastic, or linoleum cemented down, or, at least, rendered impermeable by pouring hot paraffin wax over it, the excess of wax being scraped off before cooling (the coat of paraffin wax should be renewed from time to time). Waxing tends to make the floor very slippery when wet, however, and should be avoided if possible.

At the bottom of each wall, the waterproofing on the floor can usefully be swept up the corner to a height of 8 in. or more, thus preventing moisture seeping down the wall. It is particularly desirable to waterproof the floor thoroughly if there are other rooms below.

It is convenient to provide a drain in the floor to enable it to be thoroughly washed.

The interior walls, and, if possible, the ceiling, should be covered with a washable paint, preferably mat (many water paints withstand water after complete drying) of a light colour—but not white, as it gets dirty so easily, and occasions reflections, which may cause trouble when the darkroom is used for enlarging. Yellow and cream are the most suitable. They remain light whatever illuminant is used (red or green). It is well to cover the wall at the back of the sink with earthenware tiles or thin sheet lead to protect the wall from splashes. Ceilings should preferably be between 9 ft and 11 ft in height and should never be whitened with ordinary distemper as this powders and is a common cause of "pinholes" in negatives. Enamel or oil-bound distemper is satisfactory. Ducts and conduits should be kept away from the ceiling when possible.

If possible, the darkroom should have a window for ventilation when the room is not in use. The easiest way of excluding light is to replace the panes of glass by tin plate or plywood or to paste black paper over them; or a blind may be fitted between two frames, forming

a trap for the light; or a detachable shutter may be constructed of plywood or by gluing opaque paper on cloth stretched on a framework, which, in turn, may be wedged in the window frame or secured by screws and bushes.

270. Passages. Where there is ample room, it is a great convenience to provide means for entering and leaving the darkroom without admitting light. One method is the *revolving door*, as shown in Fig. 20.1, the vanes closing on

without admission of extraneous light to the darkroom, it is convenient to be able to pass slides containing exposed plates from the studio to the darkroom, or re-loaded slides from the darkroom to the studio, without having to admit white light to the darkroom. An arrangement as shown in Fig. 20.4 can be built in the partition for this purpose. It consists of a wooden box with a false bottom and two openings opposite each other; a flexible

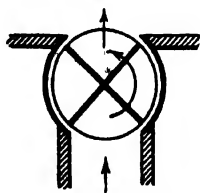


FIG. 20.1

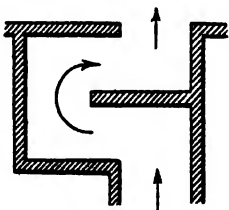


FIG. 20.2

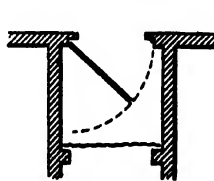


FIG. 20.3

TYPES OF ENTRANCES TO A DARKROOM

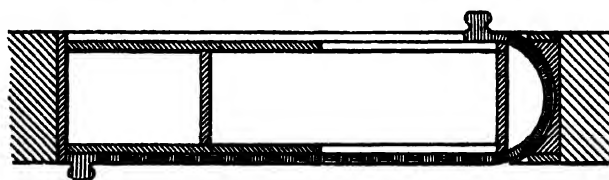


FIG. 20.4. BOX FOR LIGHT-TIGHT DELIVERY TO A DARKROOM

one another for ventilation when the darkroom is not in use. Revolving doors are not advisable unless the darkroom has an emergency exit freely accessible for use in case of danger. Another plan is a series of partitions represented in Fig. 20.2, the centre partition, at least, being preferably movable to admit large objects. If neither of these means are possible, one must be content with an ordinary door (Fig. 20.3) opening into an enclosure, covered with a large opaque black cloth, hanging in folds and arranged if possible against a frame which forms a species of rebate. Room can be saved by the use of two sets of such curtains, one in place of the door. Curtains should be hung well above the level of the top of the entrance, to ensure easy entry, and should be made of thick, limp, opaque material, preferably weighted at the bottom. Whatever the means adopted, the walls of the "passage" must be painted mat black to absorb as completely as possible any light that may reach them.

If entrances and exits cannot be made

curtain of strips of wood mounted on cloth is arranged so that one opening cannot be uncovered until the other has been completely closed.

Another device for the same purpose is shown in Fig. 20.5. Within the thickness of a partition wall a kind of cupboard is arranged, closed on each side by a guillotine or sliding door. A cylindrical iron rod, sliding in grooves, forms a common bolt between the two doors, one of the latter being able to slide only after a peg in the bolt has been fitted into a hollow in the other door, which is thus locked. When one door is open the bolt cannot be disengaged from the other, since it is flush with the inside wall of the open door.

Use has been made for the same purpose of a drawer opening from either side of the partition, and sliding in a sheath long enough to cover it entirely.

271. Ventilation. Except in the case of darkrooms having permanent entrances by "passage" the exclusion of all light obviously

necessitates the closing of all the means of ventilation usually found in a room. It is therefore necessary to arrange a system of ventilation which does not allow the passage of light, by air-ways to another room, or preferably to the open air.

In the more elaborate premises proper air-conditioning may be installed and this is ideal



FIG 20.5. BOLT FOR SELF-LOCKING DARKROOM DOOR

provided the plant is of sufficient size and properly fitted. In other cases, two systems are required, one for the entrance of fresh air, and the other for the removal of the contaminated air, the former near the floor of the darkroom and the latter near the ceiling.

When the ventilation is taken from a corridor or from another room, the partition is provided with a wooden frame similar to that shown in section in Fig. 20.6. The passages are formed by thin sheets of wood or metal mounted in the frame. When the ventilation is taken from the open, the wall is fitted with hollow bricks (Fig. 20.7), the passage being made on the outside by a zinc baffle plate, and, on the inside, by a wooden frame with a wood or iron panel. In both cases all inside walls of the passages are painted mat black to avoid successive reflections of light.

Ventilation to the open may also be made by shafts or wide tubes of wood or sheet iron with bends, so as to exclude the light.

Apart from providing entry and egress for air, it is desirable to ensure that a constant flow through the room is maintained. Suitably designed ventilators will do this to some extent but the use of an electric exhaust fan in a ventilator in or near the ceiling is more efficient. A six-inch fan is sufficient for small rooms but a nine-inch or larger fan should be used for bigger rooms. Each fan should be light-trapped by baffles similar to those in Fig. 20.7.

272. Heating. The temperature of the baths used in photography considerably affects the speed of the reactions and the quality of the

images. The use of time methods of working requires the temperature of the developer to remain practically constant from one operation to another, or at least during a single operation. It is useless to try to use a warm developer in a cold darkroom, or vice versa, except by employing a water-bath of large capacity.

The best way is to keep the temperature of the darkroom constant within narrow limits (about 68°F). If full air-conditioning or central heating is not available, the flue of a stove in a neighbouring room may be arranged to pass through the darkroom. A closed combustion stove in the darkroom is a mistake, on account of the dust produced in charging and discharging. Failing other means, an electric heater may be used; special types of portable electric stoves are available which give out no light and tubular heaters can be used round the walls. Thermostatic control of the room temperature is

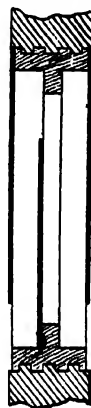


FIG. 20.6

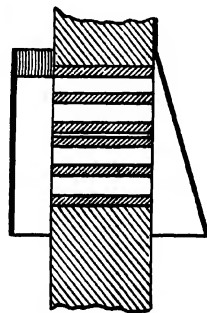


FIG. 20.7

DARKROOM VENTILATORS

advisable when using fixed heaters. Electric immersion heaters are very useful when one wishes to warm up rapidly a very cold bath to the temperature of the darkroom. They are heated internally by resistances, and are plunged into the liquid to be heated, and used as a stirrer.

273. Sinks. It is best to conduct all operations with liquids in a large sink. This can be made, for example, of wood, lined inside with lead (all joints must be welded, not made with tin solder), slate, rubber, asphalt or a plastic such as Alkathene. It is possible to use sinks of bare pine, the boards being held firmly together by bolts passing the full width of the

sink. It is sometimes advisable to use a jointing of thick tar in the grooves of the joints. Cement sinks are to be avoided; they are cheap but do not last long; earthenware sinks are usually too small. Chemical stoneware sinks of adequate size are made. Stainless-steel sinks are satisfactory provided chemically-resistant steels are used and that the sinks are entirely seamless or at least welded and polished; such

various baths, it is convenient, for diluting stock solutions at the time of use, to have a separate container of about two gallons capacity, in which the water can come to the temperature of the darkroom and give up at least a part of the gases dissolved in it.

The waste pipe should preferably be covered with a perforated dome-shaped cap, to prevent its stoppage by odd pieces of film or paper.

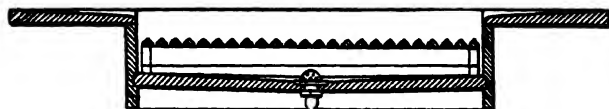


FIG. 20.8. DARKROOM SINK

sinks are rarely available in the larger sizes. The bottom of the sink should always be on a slope, to allow all the water to flow away through the waste pipe (Fig. 20.8).

The sink is provided with a wooden rack from one end to the other, fitted with triangular rods, so that it makes very little contact with the bottoms of dishes, and consequently does not wet them appreciably.

The internal dimensions of the sink should be such that it will hold side by side the dishes used in the various operations. It should be 6 to 9 in. deep and should not be less than 2 ft 6 in. from the floor. The sink may be extended on one side or the other by draining-boards where stock solutions can be mixed. These should preferably be made of impermeable material such as stainless steel or teak, or be rendered impermeable by hard rubber or rubberized cloth, and should have grooves draining into the sink to prevent water collecting on them.

Cold water should be laid on, if possible, from two taps; one supplies the washing tank and is arranged at one end of the sink, while the other, near the centre, is used for mixing solutions, rinsing, etc. In a darkroom often used for the handling of large plates it is an advantage to be able to operate one of the taps by foot to give the operator free use of both hands. A hot-water tap, while not essential, is often useful. It is well to choose taps of a long-neck pattern, and to fix them so that they project from the wall to about the middle point of the sink, placing them at a height such that they allow the passage under them of the tallest vessels used when standing in the bottom of the sink or on the grid. The water supply being usually at a lower temperature than that best for the

If it is wished to wash large prints in the same sink, it is useful to fit a support for a vertical tube in the waste pipe, the arrangement serving the purposes of an overflow. The waste pipe should also be provided with a trap, with an inspection plug at each bend, in case the pipe becomes stopped up.

Lead pipes should be used for the smaller waste channels and earthenware pipes for the larger drains. Iron pipes are corroded quickly. Open, glazed gullies between the lead pipes and the main drains are convenient for cleaning and inspection. Photographic solutions can, in general, be discharged into the normal drain system unless very large volumes are involved, in which case the local authority should be consulted.

274. White Light in the Darkroom. Apart from the safelights for the darkroom, which we have studied in Chapter XIX, there must obviously be ordinary lighting, chiefly for cleaning, getting things ready, and examining negatives, etc., after fixation. Where electric light is used, steps must be taken to avoid confusion, during working, between the switches operating the white light and those operating the safelights. The switches for the white light may be boxed in or operated by removable keys, or may be placed higher than the others, or be of a different design and material. It is possible, for example, to use a foot-switch to light up momentarily a lamp with a white or bluish ground glass window used for examining negatives and prints immediately after fixing.

To avoid dazzling the eyes and rendering them slow in getting accustomed to the safelight, any white lights in the darkroom should be provided with ground glass or opal diffusers, so as to

render the filaments or flame indistinguishable. The lamps should be arranged as high as possible so as to be out of the direct field of view.

275. Equipment of the Darkroom. It is a good rule that the darkroom be used only for operations which cannot be performed except in safelight. An extra "work-room" should be provided, with a sink and one or two tables and cupboards, for any work which can be done in white light, e.g. weighing chemicals, preparing baths, intensification and reduction of negatives, toning, and washing prints, and drying. If the darkroom and workroom are next to each other, the sink may be extended through the partition by making a passage through the partition. This should be of a size to allow space for a dish between the grid and the top of the aperture. The amount of light which can thus enter the darkroom will not be serious if the communication with the workroom is made in the darkest corner of the latter; a movable trapdoor or a blind of rubber cloth may be used as a safeguard. But let it be borne in mind that neither of these rooms, where the atmosphere is always somewhat damp, is suitable for keeping stocks of plates, papers, etc. There should, however, be one or two drawers in the table, for use when loading slides, for opened packets, and sufficient material to last the day only.

The table used for loading and unloading slides should be far enough from the sink to be out of the range of any splashes, and not in the direct rays of the lamp. In a very small room, a folding table with a cloth cover can be used, being erected only when required.

Where possible, all benches and other woodwork should be of birch, maple, beech, or teak, the last being best for wet positions. The woods are more resistant when waxed, all surplus wax being rubbed away. If other woods must be used, they should be covered with a protective material such as linoleum or thick rubber-sheet or, if exposed to solutions, plate-glass, lead or stainless steel. A convenient height for tables is 2 ft 6 in. to 3 ft. Cupboards may be placed

underneath provided space is left for the toes. Benches used for solutions and those for dry operations should be carefully segregated.

The darkroom should contain only what is absolutely necessary in order to facilitate working in the dim light. All useless shelves and cupboards should be vetoed; they only encumber a darkroom and make it difficult to keep it clean. A rack suitable for draining dishes under the sink, a shelf above the sink for bottles of solutions, and under this shelf a rack with notches to hold measuring and other glasses upside down, form, with the table for loading dark slides, the only necessary equipment of a darkroom used for negative-making.

If printing is to be done in the same room, there must obviously be provided a printing box and a cupboard for the printing frames and opened packets of papers. If no other room is available, there is also the enlarger to be included which may, however, be of the vertical type, and thus save space.

For ease in cleaning, avoid securing to the walls any fittings which can remain unattached. For the same reason, tables and shelves should be painted with some washable preparation, or covered with linoleum, so that they can from time to time be sponged with a wet rag. It is even well to get rid of sharp corners in the room by nailing into them strips of wood of triangular cross-section. Sheets of fibro-cement form excellent darkroom tables if painted with bitumen or other waterproof paint. Sheets of rubber cemented on to tables of hard material greatly reduce the risk of breaking glassware.

A soap dish above the sink and a roller towel on one of the walls should not be forgotten. *It is absolutely essential to rinse the hands in clean water before drying on the towel after contact with any chemical substance, dry or in solution.* This precaution is particularly necessary in the case of the fixing bath, which by contamination of the towel is the cause of many failures through handling sensitive films with fingers which are supposed to have been wiped clean.

CHAPTER XXI

DARKROOM ACCESSORIES

276. Tanks and Dishes. If only one or a very few negatives are treated at a time, the plates or cut films may be laid flat in a shallow dish, but when large numbers are often treated at once much time is saved if they are placed in a deep tank holding several plates vertically.

Dishes are made with the sides splayed outwards, and with a lip at one of the corners for pouring the liquid out. The sides of dishes are often made too much splayed out, to facilitate the packing of one inside the other for transport and storing. It is thus very difficult to move a dish half full of liquid or to rock it even gently without spilling some of the liquid. The fluting on the sides of glass dishes concentrates locally on the sensitive emulsion the light reaching them obliquely, thus sometimes giving rise to fogging restricted to narrow black shaded bands along one edge of the plate or film. The dishes most frequently used are not deep enough, especially in large sizes; the depth being usually the same for a dish 20×24 in. as for one 5×4 in.

For many years it was usual to make projecting ridges on the inside of the bottom of the dish to facilitate the removal of the plates. This practice was a nuisance in the use of papers and is now almost entirely abandoned. In its place we have a depression in one corner of the dish, which allows for the introduction of a finger nail or a hook under the plate to lift it.

Tanks for vertical development have for a long time been made with grooves in the two opposite sides, or carrying a movable framework fitted with grooves. One plate is inserted in each pair of slots or sometimes two back to back. This is not practicable with backed plates as they will stick tightly together. The removal of the plates by their edges is not always easy, and the grooves are often very close together, thus reducing the quantity of liquid in contact with the sensitive film under treatment. These types of vessels, moreover, cannot be used for cut films.

A developing tank invented for the use of the French Military Aviation (E. Cousin, 1914) was a marked improvement on vessels for vertical development then known; it was adopted afterwards by the various allied armies, and its

use has spread in all branches of photography, either in its original form for plates, or, after certain modifications, for cut films.

The plates or films are placed singly in metal frames or hangers (Fig. 21.3), where plates are held during all the operations until drying, or even including drying, in the case of films. The frame shown in plan and elevation in Fig. 21.3 is of the type used for plates. To assure a better hold on a film after it has been softened by wetting, curved frames may be used, or, for large films, frames with a deep rebate (which can then be perforated to allow free circulation of the liquids) or frames with spring clips at the four corners. If curved frames are used the emulsion side of the film must be the concave one. The frames, once filled, are introduced one by one, and left for the time necessary in the different baths and in the washing tank. Hangers are supported by their crosspieces on the top edge of the tank or on an internal ledge (Fig. 21.2), the latter arrangement facilitating the fitting of a light-tight lid, which enables white light to be turned on in the darkroom during development, if need be. To avoid air-bells both plate and film hangers can be introduced at an angle (not vertically). As soon as the whole emulsion is wetted the hanger is lifted up and down a few times. The hangers must not be too close together; a gap of $\frac{1}{8}$ in. for plates 7×5 in. or about $1\frac{1}{4}$ in. for plates 15×12 in. should be left.

The tanks should always be of such size that the plates are covered by at least $\frac{1}{8}$ in. of liquid and allow $\frac{1}{8}$ in. of liquid below them, for the accumulation of used developer or the deposition of sediment and insoluble matter.

The capacity of these vertical tanks is considerable (about 3 gallons for 12×10 in.), and it would be ridiculous to pour the by no means exhausted developer into a bottle every time it is used, to protect it from spontaneous oxidation. A very ingenious way of protecting the developer consists in placing in the tank, when not being used, a *floating lid* (shown in position on the tank in Fig. 21.1). This lid fits in the vessel with as little play as possible, thus reducing the surface of liquid in contact with the air. A floating lid can be improvised by

cutting a piece of waterproof paper (paraffin waxed paper) of size about $1/16$ of an inch smaller than the internal dimensions of the vessel. This paper can be replaced when it becomes damaged.

It is easy to treat in a given tank plates or films of any size smaller than those provided for. Hangers for plates 7×5 in. upright can

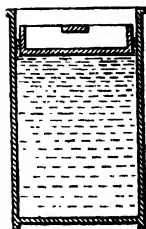


FIG. 21.1

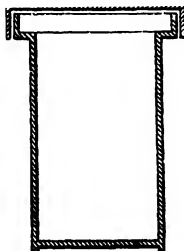


FIG. 21.2

DEVELOPING TANKS

be used for plates 5×4 in. on their sides. Tanks can also be made to take frames of various sizes, for instance, 7×5 in. lying on their side, lengthways; or 5×4 in. upright, crossways. Also, movable crosspieces may be fitted on which to rest frames smaller than those intended.

277. Special Tanks for Roll-films. A description of all the methods for developing of roll-films would carry us too far afield. For the amateur's roll-film we have tanks into which the film may be introduced in daylight, no darkroom being required. For cinematograph films we have frames immersed in a large vessel, or horizontal drums, with the film wound on them, revolving on an axis. The lower part only is immersed in the bath, and the steady rotation ensures uniform action on the film. Different types of apparatus for the treatment of the amateur's spools singly will be found in any catalogue of photographic apparatus; for equipment of the cinematograph laboratory we must refer the reader to special works. In general all tanks for lengths of film employ either a frame (round which the film is wound) or an apron of waterproof material (inside which the film is wrapped but separated from it by corrugated edges) or two flanges forming a spiral channel (into which the film is wound).

The commercial processing of roll-films (developing and printing) for the amateur is generally done in deep tanks, the films being

held by clips hung on a rod, by single hangers, or by racks holding several films. Long films are often fastened at both ends by the same clip, the two sides being held apart by a cylindrical roller weight or by a cross-piece of the frame. In case a film should drop to the bottom of a tank, a net or basket is sometimes kept at the bottom from where it can be drawn up by cords or rods hooked on the upper edge of the tank.

For long strips of film used in automatic cameras for aerial photography, too large to be handled on frames similar to those used in cinematography, apron or spiral tanks of special design may be used, or a particular type of tank, designed for aero-film, in which the material is wound forward and backward, from one spool to another, under the developer. Such a tank is standardized in the Air Forces of several countries.

We may finally mention, without describing any of the many types, the machines for processing (including fixing and washing) ciné film, film in long strips for aerial photography, and roll-films used in cameras for amateurs.

278. Materials for Tanks, Hangers, and Dishes. Material for photographic equipment has to be chosen for its resistance to the chemical solutions to be used with it, any effect it may have on

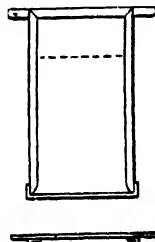


FIG. 21.3

FILM OR PLATE HANGER FOR DEVELOPING TANK

such solutions and the cost and ease of fabrication of the material itself. Owing to its absolute impermeability and resistance to nearly all chemical reagents, *glass* is certainly a good material for the manufacture of tanks and dishes, at least in the smaller sizes required by the amateur. After proper cleaning, a glass dish can retain none of the products it previously held, and can therefore be used alternately for very different operations without risk of contamination; it is, however, somewhat fragile.

Transparent glass dishes are sometimes used in order to be able to illuminate the negatives from below in the course of development or fixing in order to follow the progress of the operation without touching the plates.

Porcelain (white translucent ware) has the same properties, but is no longer used for dishes and tanks. Dishes sometimes described as "porcelain" are nearly always made of some variety of earthenware (opaque porous ware) with the surface protected by a glaze, which is fragile and easily chips off. This glaze readily cracks, allowing the products to penetrate into the porous substance, whence they can only be partially removed by washing, or even by the action of powerful reagents. Not only should an earthenware dish be kept as far as possible for the same bath, but one should avoid leaving the solution in it longer than is necessary for the operation; for if a solution of a salt is left in such a dish it tends to crystallize out in the earthenware, breaking up the glaze and sometimes even the earthenware itself. This does not apply, however, to the special stoneware made for the chemical industry and used for the manufacture of vertical tanks for handling numbers of roll-films at a time. These are excellent for use with most photographic solutions but they should not be used with caustic alkalis.

Brief reference may be made to tanks and dishes of celluloid or of moulded composition. These nearly always split or become deformed after using for some time. These dishes must never be used for baths containing caustic alkali or a large proportion of alcohol. Some of the newer plastic materials are, however, excellent.

Slate is excellently adapted for the construction of dishes of large size, being strong and having perfect resistance to almost all chemical reagents.¹ At the same time, it is very necessary to protect the edges of the tanks used for fixing to prevent the hypo from penetrating into the material along the planes of cleavage, and separating the layers when it crystallizes. This, however, only occurs after very long use. Resistance can be increased by impregnating the slate with paraffin wax, applied very hot.

Tanks of *reinforced concrete* faced with cement are useful for washing; they can also be used for development in dilute baths or baths only slightly alkaline. They are attacked by fixing baths, particularly acid fixers, as well as by all

acids in very weak solution. They can, however, be coated with a chemical-resistant paint or with hard asphalt, which considerably increases their life.

Dishes of *wood lined with gutta-percha* about a quarter of an inch thick are satisfactory in large sizes by reason of their lightness and strength. They are not much use, however, in hot climates, where the gutta-percha becomes very soft. If left dry for a great length of time these dishes are liable to crack, but it is easy to repair them with a hot iron. The material known as Wigan cloth is also very satisfactory for lining dishes. Wooden dishes may be made impermeable with molten paraffin wax applied very hot with a brush and smoothed on the surface with a hot iron; also with several coatings of asphalt varnish, allowed to dry with free exposure to the air before using. Plain wood, preferably one of a resinous nature (such as cypress, spruce, redwood, or teak) may be used for tanks, if the latter are metal-bound (otherwise they may leak at the joints, especially if allowed to dry), and are always kept for the same operation. The wood, being porous, does not permit the use of successive "incompatible" baths. When paraffin wax is employed to impregnate wood used for tanks, the wood should be soaked in water for a day and then immersed in molten wax at 120°C for two hours. Joints can be caulked by means of thin strips of untreated wood, which swell when the solution reaches them.

Vessels of *enamelled steel* made by manufacturers for the chemical industry resist the usual photographic reagents well. The steel does not usually become deformed, and the enamel, having the same coefficient of expansion as the steel does not tend to crack. Unfortunately, the enamel is slowly etched by alkaline solutions, even developers, and is easily chipped by careless handling. Once the metal underneath is bare its corrosion is rapid, and the enamel soon comes off in flakes on both sides of the cracks. Cheap dishes of thin metal, especially if welded, instead of being cast or pressed, are particularly prone to show such troubles.

Ebonite-covered steel, which is sometimes used for medium-sized tanks, is not open to the same objections, as ebonite is sufficiently elastic not to crack in case of slight temporary or permanent distortion of the metal. Other suitable coverings include soft rubber sheeting, asphalt paint, either alone or mixed with rubber

¹ Dishes for development and washing must be joined by cement; those for fixing, with gutta-percha.

solution, hard asphalt (applied hot), halogenated rubber paints and certain Bakelite lacquers. None of these materials is completely impervious to any solution upon prolonged exposure, however. The outsides as well as the insides of tanks should be protected.

Pure, hard rubber, free from sulphur compounds, is an excellent material for dishes and tanks. Many thermoplastics, especially those of the acrylate and cellulose types, are also very resistant and easily worked. They may, however, be distorted by hot solutions.

When bare metal is employed, the action of the metal on the bath, as well as that of the bath on the metal, has to be considered. In particular, *copper* and *tin*, with their *alloys* (with the exception of the copper-nickel alloy to be mentioned), *bronze*, *brass*, and *solder*, should *never come into contact with a developer*, since they are certain to produce an intense chemical fog (J. I. Crabtree, 1918). Rubber of ordinary quality (tubing, stoppers, etc.), which contains antimony sulphide (always present in the red variety) and sulphur, also causes fog if allowed to contaminate the developer. Pure rubber (English sheet) does not give rise to this trouble.

In considering the choice of a metal, a distinction must be drawn between a material suitable for amateurs, which is not likely to be exposed for long periods to chemical action, and one used on a commercial scale, which may be almost continually in contact with the solutions used.

Stainless steel for chemical industries containing not more than 0.08 per cent carbon (J. I. Crabtree, 1936) and about 18 per cent chromium and 8 per cent nickel, pure nickel and nickel alloys rich in nickel (Monel, Inconel) are suitable for development, fixation and washing; copper or brass thickly and evenly nickel-plated, are suitable for vessels used for development and washing; they may also be used for fixation, but the time of exposure to hypo must be strictly limited to the time necessary for fixation, and the vessels must be washed immediately afterwards. Chromium, cadmium, and silver are not suitable for plating photographic equipment as the layer is not fully resistant to solutions. Plated metals should not be used for apparatus likely to be cut or abraded; in the event of such damage, electrolytic action occurs and the plating is quickly removed. If absolutely necessary, the tanks may be soldered *externally*; developing hangers should never be soldered.

Tanks of cast iron and of mild steel have been used with advantage for developers with a strong content of caustic alkalis.

Lead is only very slowly attacked by developing or fixing solutions (the latter may contain acid, alum, or silver salts), and does not affect the solutions. In general any metal when placed in used fixing baths, as in solutions of silver salts, becomes covered with a weakly adhering film of silver, which gives only very incomplete protection against the action between the metal and the solutions in which it is immersed. Wooden tanks lined with lead (the joins must be made by welding and not with a tin solder) are very satisfactory, as are small lead-lined steel tanks. Type metal has similar properties, and may be used, particularly for taps in photographic tanks.

Zinc is not affected by pure water, but it is rapidly attacked by photographic solutions, even when very dilute. When tanks for washing are made of or lined with zinc, it is essential to restrict the corrosion of the metal by at least rinsing plates or prints before putting them into the tank. The tank should always be emptied and drained after use. Aluminium should also never be allowed to come into contact with developers or fixing baths, as a chemical reaction may take place which leads to stains on the gelatine.

In general, all metal vessels which come into contact with developing or fixing solutions should be made of one homogeneous metal. Of two metals in contact with each other and with the solution, one is always more quickly corroded than it would be alone, owing to electrolytic action. Most alloys thus suffer greater corrosion in contact with solutions than would either of the constituents separately.¹

In general, metals should not be used for photographic work unless tests show them to be suitable for the specific purpose in mind. Non-porous, non-metallic substances should be the first choice, provided they are chemically stable and do not contain sulphur or metallic sulphides.

279. Glass-ware. The photographic outfit comprises a number of glass articles, notably graduated glasses (measuring glasses, conical glasses, and measuring cylinders), the graduations of which are often marked with a pleasing disregard of exactness (the graduation of meas-

¹ Many of the data given in this section are taken from the papers of J. I. Crabtree and G. E. Mathews, published in 1923, 1924, and 1936.

uring cylinders is generally less crude than that of the conical measures, and is, at any rate, fairly uniform), stirrers (glass rods rounded at the two ends by heating), and a dropping bottle. The volume of the drop varies with the nature of the liquid and with the temperature, but it varies most with the *outside diameter* of the dropping tube. The drops given in some formulae are, as in pharmacy, the drops delivered by a *standard dropping bottle* with capillary tube of external diameter 3 mm. In a darkroom of any size funnels for filtrations are essential, and a funnel stand of wood is a useful thing; the "notch" type is preferable to the "ring" pattern.

The risk of breaking measuring glasses is greatly reduced by fitting a projecting band of rubber round the top edge.

At its upper surface a solution ascends the walls of a vessel (capillarity). The observer must read the lower surface of the meniscus thus formed, the eye being on the same level.

When using a stirrer in a vessel of thin glass it is well to cover the ends of the stirrer with a small piece of rubber tube. For mixing large quantities of liquids, a large spatula or paddle of soft wood is best, but each of these must be kept strictly for a particular bath, the purpose being marked on the handle.

For the preparation of baths it is useful to have some pots or pans of enamel ware or aluminium in which water may be heated (if hot water is not laid on), the dissolution of the chemicals being done in a bottle or in some vessel of a material resistant to the substances used. For warming-up any solutions, chemical glass-ware or porcelain basins should be used exclusively.

We shall discuss more fully in a later chapter the question of bottles and glass jars (§ 285).

280. Cleaning of Utensils. Dishes, tanks, and all vessels or utensils of glass or earthenware which have become stained are best cleaned by running a little strong hydrochloric acid all over. The acid can be used a great number of times. With a hard brush or a rubber sponge it is then very easy to remove all adherent deposits, and the cleaning is finished by rinsing in pure water and draining.¹ It is better not to wipe; the cloth used is generally dirtier than the vessel to be cleaned.

¹ Although the acid decolorizes all stains, thorough scrubbing and washing is necessary to remove the contamination, which will otherwise reappear as soon as developer is used in the vessel.

If a point is made of cleaning vessels immediately after use, it is usually sufficient to rinse them in water to be sure they are perfectly clean.

Adherent deposits on the inside of bottles can often be removed by shaking up with lead shot and a solution of sodium carbonate.

Wooden developing frames or racks placed successively in developing and fixing baths must be cleared of all traces of the hypo which has penetrated into the wood before being used again. This can be done by allowing them to remain for some time in a solution of about 80 gr. to the gallon of potassium permanganate (followed by a rinse in pure water). The same precaution can be taken with metal frames, but they need not remain so long in the bath. The silver which is deposited on the metal frames forms an uneven layer liable to stick to the gelatine of the negatives. It is best to remove the large deposit of silver from time to time by means of a steel brush. After this, proceed with the treatment indicated above, and then brush with a tooth brush, rinse in water, and put to dry.

Metal tanks can, if cleaning with water is insufficient, be rinsed occasionally with hydrochloric acid diluted with about ten times its volume of water, but the vessel must not be allowed to remain in contact with this acid bath too long. For stainless steel use fairly dilute nitric acid.

Too great emphasis cannot be laid on the necessity of carefully cleaning every new vessel before taking it into use. For the first cleaning of metal goods (except for aluminium, which can be cleaned with soap or with a solution of trisodium phosphate) hot soda solution should be used to remove the greasy material which has been employed for polishing or for the protection of the surface.

281. Various Accessories. The *racks* sold for drying negatives are usually of bad design. As a tradition from the days of wet collodion, when the photographer had to carry his entire apparatus to the place of operation, these accessories are often of folding pattern, to the detriment of their stability; their grooves are also too close together, and may be of rectangular section, whereas they should be of V-section, so as not to allow the wet gelatine to stick to the sides of the groove. For professional work, and in all cases of large sizes, the racks should be rigid, with well-spaced grooves, allowing free renewal of the air round the drying gelatine.

As regards *balances*, it is best to choose the Roberval type, such as is commonly used as shop scales, thus permitting the weighing of substances in a weighed vessel without interference of the usual stirrups supporting the pans. The sensitiveness of a balance being about a two-thousandth of the maximum weight it will carry, it is well not to buy a balance which is capable of dealing with greater weights than are necessary. If, in a large establishment, it is necessary to have balances for heavy weights, it will be best to provide a separate balance for light weights. A Roberval balance, having a very long needle, will weigh 3 oz. to 7 oz. to the nearest grain. A very practical type of balance, since it avoids the use of the very small weights, often lost, consists of a graduated beam along which a small mass can be moved as in the steelyard.

A very useful accessory in the photographic darkroom is a small clock having only a minute and second hand, both being visible in the semi-darkness of the darkroom, or, better

still, a *metronome*, set to beat half seconds or seconds. Excellent spring-driven and synchronous electric clocks are available with large seconds hands coated with phosphorescent material.

A final item of equipment is a thermometer, fixed at some distance from the wall, to indicate the temperature of the darkroom; also a small thermometer, graduated on the stem, for placing in tanks or dishes to ascertain the temperature of the baths. Alcohol thermometers for photographers should not have the liquid coloured red, but deep purple blue, in order that it may be easily seen in non-actinic light. Dial thermometers, with the bulb at the end of a flexible pipe, are available for use in tanks. Thermostatic controls can be fitted if electrical warming devices are used.

For washing, a siphon is a useful accessory. A small type can be fitted to the side of a large dish to maintain the level of water at a predetermined height. Another sort can be used in the drain-hole of the sink, for the same purpose.

CHAPTER XXII

CHEMICALS: PREPARATION OF SOLUTIONS, WATER SOFTENING, INDICATORS, pH

282. Choice of Chemicals. Substances which are entirely free from chemical impurities cannot be obtained as ordinary commercial products, and are only necessary for certain scientific investigations, for which purposes they are specially prepared by elaborate processes of purification. Intermediate between the purest chemical products and the raw materials, there are a large number of grades, which differ from one another in the amount of active constituent they contain, as well as in the nature and proportion of the various impurities. Certain impurities, according to the use for which the substance is needed, are not injurious. For instance, impurities which merely lower the amount of active substance present may be permitted, but others, which would retard or interfere with the intended reaction, should be excluded.

For this reason, chemical substances to be used in pharmacy must comply with the standards of purity laid down in the *British Pharmacopæia*. Similarly, many firms issue certain specifications to their purveyors of chemicals, which state the limits of admissible impurities in each product, and fix the price according to the actual content of active substance. It may be gathered from these remarks that care should be exercised in buying photographic chemicals, and that a comparison of prices is not the only consideration to be taken into account.

In his own interests, therefore, the photographer should purchase his chemicals from reputable specialized firms, who, from their knowledge of the ultimate uses of the materials, can supply the required qualities.

283. Anhydrous, Crystalline, Efflorescent, and Deliquescent Substances. The amount of active substance contained in a product varies considerably with the chemical form in which it is obtained, and also with the extent to which it may have been changed by the action of the air.

Many salts exist in two forms, *anhydrous* and *hydrated*, the latter appearing most usually in the form of crystals. Anhydrous sodium sulphite for example, is equivalent to exactly twice its own weight of the crystalline sulphite, the difference (assuming both substances to be pure) representing the *water of crystallization* contained in the crystalline salt. The fact that

this numerical relationship is fortuitous and applies only to the case of sodium sulphite, is often overlooked. Thus, anhydrous sodium carbonate is equivalent to 2.7 times its own weight of the crystalline carbonate, and anhydrous sodium thiosulphate ("hypo") to approximately 1.5 times its own weight of the crystalline salt.

The water, which constitutes an integral part of hydrated salts, is not always firmly retained, and, in a very dry atmosphere, certain of these salts *effloresce*, the outer coating of the crystal being converted to the powdery anhydrous compound.

Other salts, both anhydrous and hydrated, readily absorb moisture from the air,¹ dissolving progressively in the water they have absorbed. These *deliquescent* or *hygroscopic* salts, as they are called, are very difficult to keep in good condition, and their weighing-out becomes so uncertain that it is often advisable to prepare from these substances, immediately they are received, a stock solution of known concentration, from which, at any future time, the various mixtures may be prepared.

284. Unstable Substances. Many other substances change very rapidly, either spontaneously or due to the influence of atmospheric oxygen. These changes are usually accelerated by the presence of moisture. In this manner sodium sulphite, particularly as the crystalline salt or in solution (in which case the weaker the solution the more rapid the change), is gradually converted into a mixture of sulphate and dithionate by absorption of oxygen. Similarly, developing agents turn brown or black, in time, by oxidation, especially if they have been transferred to a damp vessel; cyanides are gradually converted into carbonates by the carbon dioxide in the air. In a manner similar to the loss of gas from Seltzer water, ammonium hydroxide constantly loses ammonia gas, which, dissolved in water, forms the active constituent. Solutions of formalin, or formaldehyde, deposit a white insoluble mass (trioxymethylene) produced, without external interference, by a transformation of the original gaseous product.

¹ Products like quicklime and liver of sulphur that swell in damp air without dissolving in the absorbed water may burst a badly stoppered jar.

These examples, which could be multiplied indefinitely, indicate, in the first place, that every precaution should be taken to store the substances as carefully as possible, and also that, for the majority of chemicals which are used, the actual amount of active substance present is very uncertain.

Fortunately, the ordinary photographic processes do not require great precision. A considerable variation of an active substance in a photographic bath would often pass unnoticed. It is therefore useless to discuss the relative merits of formulae differing from one another in a small degree, since the variations, which occur unknown to the operator, are in many cases much larger.

285. Storage of Chemicals. Many solid substances, which are not readily affected, are usually delivered in bags or cardboard boxes, to reduce carriage costs, but there are very few photographic chemicals which, if stored in this manner for any length of time, would not become spoiled to a greater or lesser extent. Moreover, it is not infrequently found that the labels or inscriptions on such parcels are lost or become illegible, or that the bags are split with the consequent risk of annoying losses and mistakes.

Stable substances, such as "hypo," the alums, and the various natural products, which are occasionally used, gum, starch, etc., should be stored in wooden boxes, or the bags containing them should be placed in labelled metal boxes.

All other substances should be stored in tightly-stoppered glass or earthenware receptacles. For this purpose, narrow-necked reagent bottles are very much easier to seal hermetically than the ordinary type of wide-mouth bottle. Druggists usually seal off their bottles with flat corks which are cut off level with the neck. This method, although perfect at the outset, does not afford such an airtight joint once the cork has been removed and replaced. It is therefore better to obtain, both for ordinary products and for unstable substances, a series of bottles of required capacity, fitted with good quality cork stoppers of tall conical shape, which are easily removed by hand, and will last for a considerable time. Cork stoppers can be made more flexible by rolling them under pressure between a block of wood and the top of a table: they can be readily filed down, if necessary, to improve the conical shape. A conical stopper of pliable cork affords a perfectly airtight fitting owing to the pressure which it

exerts on the glass as it is gradually forced in. When inserting the cork, about half its length should be left above the neck.

It is frequently supposed that *ground-glass stoppers* are preferable to cork. Although they must of necessity be used with certain liquids, such as nitric and sulphuric acids, which attack both cork and rubber, the fitting so obtained is far from airtight, and there is the additional risk that the stopper will stick tightly unless smeared with paraffin. This type of stopper should be avoided for alkalis and their solutions, and for very volatile liquids, such as ether. Stuck stoppers can usually be loosened by leaving the bottles for about 48 hr under a depth of about 6 in. of water, the water gradually finding its way between the stopper and the neck. Sharp tapping with a stout glass tube is another method which is often successful.

Many substances which attack cork (solutions of caustic soda and potash, hydrochloric acid, sodium hypochlorite) can be stored in perfect condition in bottles fitted with rubber stoppers. This method of storage is recommended for all oxidizable solutions.

Beer and preserve bottles can be obtained with mechanical caps, which fit down tightly on to rubber rings. These afford a perfect airtight fit, which is specially useful for oxidizable liquids and solids. It is also possible to procure rubber caps, which may be drawn right over the neck of a bottle fitted with an ordinary cork stopper, in order to render the joint more airtight.

The few substances which are unstable to light (e.g. solutions of mercuric iodide, used for intensification) should be stored in opaque bottles (either stoneware bottles or ordinary glass bottles covered with black paper).

The amateur must never store photographic chemicals or their solutions near household or pharmaceutical preparations, and it is important that they should be inaccessible to children. Bottles of similar shape to those used for beverages should be avoided, or at least the old labels should be removed and new ones indicating the contents made clearly visible. As the common photographic chemicals are not poisonous, their accidental ingestion will have no worse than disagreeable consequences.

286. Labelling of Jars and Bottles. The necessity for labelling very clearly the containers of all substances or their solutions immediately they are bottled cannot be stated too emphatically. Neglect of this elementary precaution, especially in a darkroom to which several

people have access, leads inevitably to annoying mistakes and to loss of materials which cannot be identified.

Labels written in indian ink on white paper can be rendered indelible by painting them, after the gum has dried, with a brush dipped in celluloid varnish or melted paraffin wax. If this is not done, a bottle should be held with the label upwards when pouring out liquids, so that if any of the solution should trickle down the sides the label will remain intact. The labelling of all large receptacles should be done with paint.

To avoid loss of time when renewing the stock solutions of baths which are in constant use, it is often useful to have a copy of the formula for each particular bath in the form of a label on the bottles in which they are kept. The formulae may also be copied on to a piece of white cardboard, mounted under glass and fixed to the wall near the place where the weighing is carried out.

287. Solutions, Concentration, Solubility, Saturation. A solid, liquid, or gaseous substance dissolves in a liquid when it disappears into the liquid, giving a homogeneous solution; the dissolved substance is called the *solute*, and the liquid in which it is dissolved the *solvent*; evaporation of the solvent leaves the solute unchanged.

For practical purposes the *concentration* or *strength* of a solution may be taken as the weight in grammes of the solute in 100 ml of the solution. For example, if 20 g of hypo are dissolved in a certain quantity of water and, after solution, made up to 100 ml, then this solution is said to be 20 per cent, or a 20 per cent "hypo" solution. (When the solvent is water, the fact is not usually stated.) To be correct such a solution should be labelled "20 per cent solution of hypo, hydrated" because it contains less than 20 per cent of anhydrous hypo.

At any one temperature, a solvent will dissolve only a fixed amount of a salt, and when the solution has attained its maximum concentration it is said to be *saturated*. This concentration is known as the *solubility* at the temperature in question.

Except in very rare cases the solubility of a salt increases with rise in temperature. On cooling a saturated solution, the excess of the solute over the solubility at the lower temperature separates out in the form of crystals, which are generally much purer than the original substance (purification by crystallization), since the impurities present have not been able to

reach their saturation point as long as the amount present in the salt is not considerable.

In certain cases, however, a carefully cooled saturated solution will not deposit crystals, but will remain in *unstable equilibrium*. Such a solution, called *supersaturated*, will deposit the excess of salt in solution immediately, if a speck of the same salt is brought into contact with it.

The speed of solution depends on various factors. A porous or very finely divided substance will dissolve much more readily than one in the form of large compact lumps. Nevertheless, water should not be poured on to a powdered anhydrous substance, but the latter should be dropped into the water in small quantities to prevent the formation of a large compact mass of the hydrated salt. Solution takes place more rapidly in hot than in cold water, and is accelerated by agitation. Since the solution is denser than the solvent, there is a tendency for a saturated solution to be formed in the neighbourhood of the salt unless this is suspended in a porous pot or a bag at the top of the liquid.

288. Expression of Formulae. A correctly-stated formula gives the substances in the order in which they are to be dissolved.

The quantities are expressed in weights of solid substances, or volumes (at 65°F or 18°C) for liquids. The arithmetic of compounding solutions is greatly simplified by the use of the metric (grammes, litres, millilitres) system. The use of this system is especially invaluable in avoiding confusion between Imperial and U.S. ounces, pints, and gallons. In both of these systems the ounce¹ is the same, but the U.S. pint = 16 fluid oz and the U.S. gallon = 128 oz, instead of 20 oz and 160 oz as in the Imperial (British) system. Above all, it is worse than useless to compromise, as is sometimes done, and to work with a mixed system of grammes and fluid ounces. Accordingly all the formulae in the following chapters are given in the metric system.

The weights or volumes are arranged to give a total volume of 1,000 ml. The volume of the principal solvent need not be expressly stated, but may be indicated by the instruction, "Sufficient quantity to make 1,000 ml" or some such equivalent term.

When a formula denotes that a certain number of drops of a solution are to be measured, to

¹ Note that this refers to the ounce weight. The fluid ounces differ, the U.S. ounce being slightly larger than the Imperial.

avoid confusion the number is usually given in roman figures. It is, however, better to prescribe the quantity in millilitres of a more diluted solution.

289. Water used in the Preparation of Baths. With the exception of distilled water, rain-water, and water melted from ice, the water usually at our disposal (tap, river, and well water) contains dissolved salts (chiefly bicarbonate and sulphate of lime), suspended matter (dust, rust particles from the iron pipes), organic substances of animal and vegetable origin, which in colloidal form escape the most perfect filters, and after coagulation deposit in the baths as a fine mud, and, lastly, dissolved gases, notably oxygen and carbon dioxide.

Business establishments, possessing a water supply of poor quality, but which are able to obtain distilled water quite cheaply (condensed water from boilers) should certainly use the distilled water for the preparation of all baths, since the only impurities it contains are small quantities of dissolved gas.

Amateurs and professionals, who would have to purchase their distilled water from outside sources, but who are supplied with ordinary drinking water, should use freshly boiled water for the preparation of the baths.

A few substances form traces of precipitate in presence of the calcium sulphate which exists in boiled water, but if the baths are made up in relatively small quantities it is quite easy to filter them before use.

As a general rule, therefore, distilled water is not necessary for the preparation of photographic baths, in spite of the instructions to the contrary which are given in various formulae. The only exceptions to the use of tap water are in the preparation of the stock solutions of the salts derived from the precious metals (silver, gold, platinum).

290. Methods of Purification. The *filtration* of the water does not remove dissolved substances but, if the filter is sufficiently fine, will remove all suspended matter, and thus constitutes a useful precaution in the case of water used for all photographic treatments, including washing. It should be considered as indispensable when working with miniature negatives and, in all other cases, for the final wash.

Boiling the water drives off dissolved gases and decomposes calcium bicarbonate, liberating carbon dioxide and precipitating calcium carbonate which, with calcium sulphate, forms the furry lining inside kettles and boilers. Boiling

often causes the coagulation of certain organic substances. On cooling the boiled water, air will redissolve in it.

Various processes enable the calcium and magnesium salts that are dissolved in the water to be replaced by harmless sodium salts. By other processes all the dissolved salts can be removed, the treated water then being practically identical with distilled water.

For quite a long time, boiler-feed waters and laundry waters have been *softened* by running them through a filter of *artificial zeolites* (base or ion exchangers, *Permutites*) consisting of coarse particles of sodium aluminosilicate (R. Gans, 1906) which becomes progressively transformed into calcium and magnesium aluminosilicates when in contact with hard water. The Permutite may be regenerated by bringing it into contact with a 12 per cent solution of sodium chloride (common salt) when the sodium ions enter the Permutite, displacing the calcium and magnesium ions.

In some chemical laboratories and in various industries the water is totally demineralized by electrodialysis. Equivalent results are obtained more easily using exchangers in which the salts are first transformed into the free acids by filtering the water through a bed of humic acids obtained, chiefly, by the treatment of lignite by sulphuric acid (F. Fisher and W. Fuchs, 1927). Then the acids are removed by an insoluble base whose salts are also insoluble (C. Austerweil and A. Fieldler).

291. The Sequestration of Calcium Salts. The calcium salts in ordinary waters can be transformed into soluble complexes that cannot be precipitated by the sulphite and carbonate in developers and which do not give rise to a calcium scum on drying, by adding a small quantity of sodium hexametaphosphate ($\text{Na}_6\text{P}_6\text{O}_{18}$), "Calgon" or Grahams' salt (R. E. Hall, 1934), or pyrophosphate $\text{Na}_2\text{P}_2\text{O}_7$, $10\text{H}_2\text{O}$, and tetraphosphate $\text{Na}_4\text{P}_4\text{O}_{13}$ (R. W. Henn and J. I. Crabtree, 1944). To sequester a given quantity of calcium salts it is necessary to use rather more of the pyrophosphate than of the other two.

These salts, which are stable in the solid state when they are stored in dry air, hydrolyse slowly in aqueous solution with the formation of orthophosphates which give a precipitate of aluminium phosphate with the alum in hardening fixers. The hydrolysis is more rapid in warm solutions or in very alkaline or acid solutions.

The feebly acid hexametaphosphate hydrolyses to the acidic monosodium phosphate. The feebly basic pyrophosphate hydrolyses to the basic disodium phosphate. The tetraphosphate, whose solutions have a pH (§ 293-296) of about the same value as that of the low-activity developers, gives an equimolecular mixture of the mono- and disodium phosphates ($pH = 6.5$). The tetraphosphate is thus the only one of these three products which, in itself, or in the form of its hydrolysis products, does not affect the activity of developers. Therefore, the tetraphosphate is the only product considered in the following discussion.

In the developers made alkaline with borax (the fine-grain developers), and prepared from waters which should not be too *hard* (i.e. they should contain less than 0.2 g of calcium salts per litre; if the content is as high as this, the water needs softening) the optimum concentration of the tetraphosphate is 0.05 per cent in terms of the working strength solution. In the carbonate developers the concentration of tetraphosphate should be increased to 0.2 per cent. In developers containing caustic alkalis, the calcium salts do not generally precipitate and there is no need to add tetraphosphate.

The hydrolysis of $\frac{1}{4}$ of the tetraphosphate, at $20^{\circ}C$, requires 3 years in feebly alkaline developers and 18 months in carbonate developer, these periods being much longer than the normal storage times. In warm climates these periods are considerably shortened (at $32^{\circ}C$) to 9 and 3 months respectively, but the hydrolysis can be retarded by adding to the developer some sodium citrate (from 2 to 4 times the weight of the tetraphosphate) which, in this low concentration, has no harmful effects on the hardening properties of the fixing bath.

The concentration of tetraphosphate should be about 0.05 per cent in the final rinse, applied after washing in hard water.

292. The Control of the Alkalinity or the Acidity of Solutions. For a long time the various substances in nature have been classed as acid, neutral, or basic (alkaline). Even with the qualifying terms "strong" and "weak," these expressions do not suffice to define precisely the state of a solution nor are they specific enough to allow solutions of equal activity to be prepared when the degree of acidity or alkalinity has a considerable influence on their behaviour, as is the case in some photographic processes.

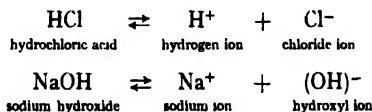
The usual *indicator papers*, a typical one

being *litmus paper* which turns red on being moistened by an acid solution and blue when made alkaline, give no idea of the degree of alkalinity or acidity. Acidimetric and alkalimetric titrations determine the concentration of an acid or alkali in solution without differentiating between substances, e.g. hydrochloric and acetic acids, which give very different results in practice.

A simple experiment reveals a phenomenon which cannot be explained on the basis of the traditional notions of acids and alkalis. When acetic acid is added to a solution of sodium thiosulphate (hypo), the hypo is instantly decomposed with the precipitation of sulphur. If, before adding the acid, a quantity of sodium acetate is dissolved in the hypo solution, the mixture will remain perfectly clear. Yet a sodium acetate solution is neutral to litmus and an acidimetric determination shows that all the acetic acid that was used is available in the hypo solution. Under similar conditions the addition of a chloride would not protect the hypo against the adverse effect of an addition of hydrochloric acid.

293. The Concentration of Hydrogen Ions.

When an acid, a salt, or an alkali is dissolved in water, it dissociates, at least partially, into *ions*. These ions consist of atoms, or groups of atoms having negative or positive charges which greatly modify their properties, for example—



In this way, all acids liberate hydrogen ions and all alkalis liberate hydroxyl (OH) ions. It is the concentration of the ions thus liberated that determines the true alkalinity or acidity of the solution. All acids and all alkalis do not dissociate into ions to the same degree. For example, the "strong" hydrochloric acid, and the "weak" acetic acid, dissolved in equivalent concentrations in water at $18^{\circ}C$, are *ionized* to the extent of 91.4 per cent and 1.34 per cent respectively.

Pure water dissociates into hydrogen and hydroxyl ions, but to an extremely small degree. Only one gramme-molecule of water, i.e. nearly 18 g, would be dissociated at $20^{\circ}C$ in 10,000,000 litres of water. This can be expressed in another way by saying that pure water contains, per litre,

10^{-7} or 10^{-7} g ions of hydrogen ions and hydroxyl ions.

The equilibrium conditions for water require that the product of these concentrations, if some circumstance causes a change in either of them, should remain constant at nearly 10^{-14} (from 10^{-12} to 10^{-15} as the temperature changes from 0°C to 100°C).

A liquid is regarded as acid or alkaline according to whether the concentration of

the activity in solution of a strong and a weak acid is considerably increased if the sodium or potassium salt of each acid is added to its solution. A salt of a strong base and a weak acid will ionize in solution. The acid ions thus liberated restrict the degree of ionization, already small, of the weak acid. On the other hand, a salt of a strong acid and a strong base, though it ionizes freely, has little or no effect on the very highly dissociated strong acid. The

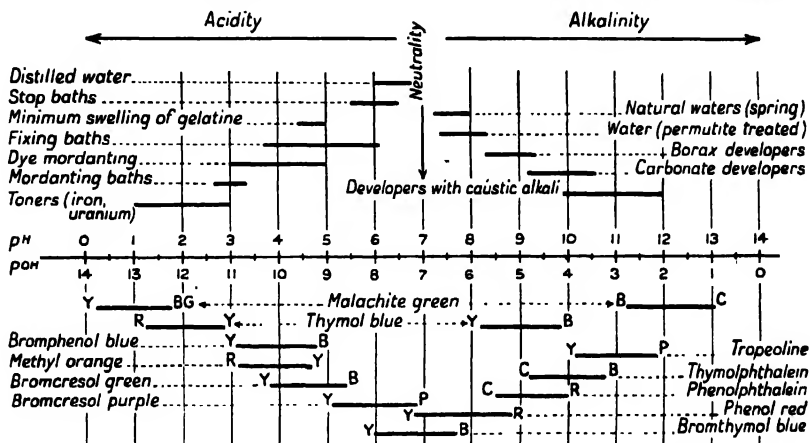


FIG. 22.1. THE pH RANGES OF VARIOUS PHOTOGRAPHIC BATHS AND SOLUTIONS OF CHEMICALS AND INDICATOR DYES

hydrogen ions or hydroxyl ions exceeds 10^{-7} g ions per litre. The product of these two concentrations being always 10^{-14} , it is possible, instead of referring to the concentration of hydroxyl ions in an alkaline solution, to refer instead to its hydrogen ion concentration, as in the case of an acid solution. In this way it is possible to measure all degrees of alkalinity and acidity on one common scale (Fig. 22.1).

294. Acidity Index (pH). Because of the smallness of these ion concentrations and the very wide range between the extreme values, it is convenient to use a more compact means of expressing them. For this purpose the term pH (introduced by Sørensen) is used where

$$\text{pH} = \log_{10} \left(\frac{1}{\text{Hydrogen ion concentration}} \right)$$

Neutrality is then represented by 7, the various degrees of acidity by numbers less than 7, and the various degrees of alkalinity are represented by numbers greater than 7.

295. Buffering Effect. The difference between

results of the experiment described above (§ 292), where the sodium acetate acts as the buffer, can be explained in this way.

In general, the term *buffer solution* is applied to solutions in which a small variation in composition results only in a negligible change in the pH.

296. The Measurement of pH. The pH can be determined precisely only by electrometric means, and in the case of solutions containing sulphite it is necessary to use a glass electrode in conjunction with a valve electrometer. Such instruments are marketed under the name "pH meters."

The use of coloured indicators serves to give only an approximate indication of the pH in photographic solutions. The effective range of a number of such indicators is shown in Fig. 22.1. The colour changes are indicated by the letters C (colourless), P (purple), R (red), Y (yellow), O (orange), BG (blue-green), and G (green). It will be seen that two of these indicators have two ranges of colour change.

297. Preparation of Photographic Baths. For the weighing-out of small quantities, the balance pans are covered with small sheets of paper, which are renewed for each fresh substance. To avoid the formation of dust, each sheet is wetted under the tap before being thrown away. For large quantities the substance is gradually introduced into a weighed and counterbalanced receptacle. Where a substance is obtained regularly in crystals of approximately the same dimensions it is possible to replace weighing by the more rapid method of a measurement of volume. Metal or strong cardboard boxes

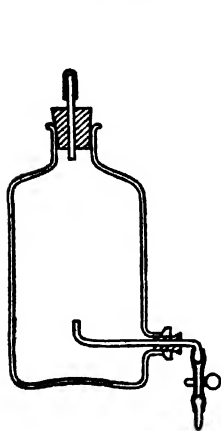


FIG. 22.2

CONTAINERS FOR STOCK SOLUTIONS

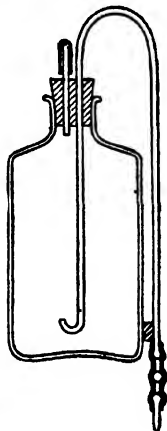


FIG. 22.3

are cut down until they will just contain the required weight or sub-multiple of the weight of substance when filled level with the sides.

A bottle large enough to contain the total volume of the bath is half or two-thirds filled with freshly-boiled warm water, into which the substances are introduced in the prescribed order with constant stirring, taking care that each substance is fully dissolved before the next is added. After the complete solution of all the constituents, the bottle is filled with boiled water and, if necessary, the solution filtered or decanted off.

Never pour water on to a powdered anhydrous salt as this, in becoming superficially hydrated, is covered with a compact crust, dissolving then being extremely slow. To dissolve such products (such as sodium sulphite and carbonate) quickly, throw them into the water a little at a time with constant stirring.

For the preparation of baths in large quantities, the work is carried out in a large vessel or tank, in which the final volume is adjusted either to a mark on the inside of one of the walls or to a notch on the handle of a wooden stirrer placed in contact with the bottom. Having introduced a certain quantity of water, the substances, contained in a linen net fixed on a wooden frame, are successively dissolved by sprinkling them with water. When all the constituents are dissolved, the level is brought up to the mark by the addition of the requisite amount of water.

298. Filtration. Filtration through paper is usually much slower and more costly than through either fabric or absorbent pads. The process is best carried out in a wide funnel (cone 60°) with a cylindrical stem, which is plugged with a piece of cotton wool or a lightly compressed piece of sponge, or, alternatively, the cone of the funnel may be fitted with a flannel or chamois leather bag. The three last-mentioned materials may be used repeatedly, if washed in running water and set to dry immediately after each filtration.

With large bulks of liquid, filtration is usually done through felt pads, each pad being kept for a special solution. In such cases, however, it is often preferable to stand the solution in a reservoir with a tap fitted at a little distance from the bottom. After the solution has cleared by sedimentation the top layer is drawn off, and it is then only necessary to filter the small quantity at the bottom, which contains the sediment and any surface scum. The decantation may also be carried out by a siphon.

299. Stock Solutions. Stock solutions may be used with advantage for all substances which are as stable in solution as in the dry state, and which are constantly being used in small quantities at a time. Weighing is then replaced by a measurement of volume, calculated from the concentration of the solution.

It has often been proposed to use saturated solutions for stock solutions, but their concentration, although well defined if maintained at a constant temperature, is liable to considerable variations. The salt, which crystallizes out on cooling, is often deposited in a difficultly soluble mass, so that when the temperature rises again the solution is no longer saturated. All concentrations which exceed the saturation value at 40°F, the lowest temperature usually reached in any commercial

establishment, even during the interruption of work at the week-end, should therefore be avoided in the preparation of stock solutions.

Stock solutions may also be prepared for unstable substances, but sufficient only for one week should be made up, bearing in mind the fact that concentrated solutions keep much better than dilute solutions (this is the case with sodium sulphite and sodium sulphide).

To avoid the necessity of handling a large bottle when only a small quantity of liquid is required, the stock solutions may be stored in bottles fitted with either a glass tube outlet at the bottom or a piece of glass tubing, which, after passing the neck of the bottle, is bent round to form a siphon (see Figs. 22.2 and 22.3). In either case, the outlet is connected to a glass jet by means of a length of rubber tubing, which is closed by a spring clip or by the insertion of a glass bead. In the latter method, the liquid is delivered by pinching the rubber tubing round the bead.

When baths are prepared immediately before use by the admixture of stock solutions, insufficient care is often taken to secure a perfectly homogeneous mixture. This cannot be obtained merely by pouring out the solutions (which have been measured together in a graduated measure) into another receptacle, for the mutual penetration of many solutions is much slower than is often realized. The mixing should be carried

out in a measure which is closed securely with the palm of the hand, and then inverted several times, or the liquid decanted several times from one container to another.

300. Commercial Preparations. A large number of preparations in various forms have been put on the market to relieve amateurs of the necessity of weighing the various chemicals for the solutions—

(a) Solutions ready for use, or concentrated solutions to be diluted with water as directed.

(b) Dry powders contained in boxes, sealed or stoppered bottles and tubes, and wax-paper packets.

(c) Compressed tablets, to be crushed between clean paper before introduction into the volume of water indicated.

(d) Homogeneous pastes, prepared by mixture with glycerine or dextrine solutions, delivered from flexible metal tubes similar to those employed for tooth pastes. A definite length of the paste corresponds with a certain volume of the particular bath (Guillemot, 1900).

(e) Paper ruled off into squares and impregnated on both sides, each square corresponding to a certain volume of the bath (Ziégler, 1901).

Owing to the diversity of the formulae used in these preparations, the only advice which can be given is to adhere strictly in each case to the accompanying instructions.

CHAPTER XXIII

HANDLING OF SENSITIVE MATERIALS LOADING AND UNLOADING OF DARK SLIDES: REPACKING

301. Storage of Sensitive Materials. Sensitive materials should be stored in a dry place of moderate temperature, where they cannot be reached by any gases or vapours from volatile products. They should especially be protected from hydrogen sulphide (cesspools, or any work where sulphides are in use) and the impurities from acetylene. As has already been emphasized, the darkroom and rooms reserved for preparation and storage of chemicals are not the most suitable places for storing sensitized photographic materials.

In an establishment of any size, the boxes should be stored on their sides in cupboards, or on racks allocated for this purpose. This avoids any possible damage to the packings, caused by the boxes being piled one upon the other. The different types of materials should be classified according to the emulsion number.

Although most sensitive materials are packed with a waxed wrapper for protection against moisture, damp storage conditions should be avoided as far as possible. Moisture lowers the sensitivity quite appreciably and, if humidity is high may cause surfaces in contact to adhere. In special cases the emulsions may be protected from moisture by covering the sensitive layer with a fatty acid, which can be removed in the developer by the saponifying action of the alkali. A somewhat similar method has been used by spies especially, in which the plates are covered with a coating of grease or varnish, development being impossible if the operator does not know that the impermeable superficial coating must be removed. Heat and the majority of chemical products cause fog in sensitive materials which is greater with the more rapid emulsions.

Even under perfect conditions sensitive materials deteriorate and the change is usually more marked on films. The edges become fogged, and, as ageing proceeds, the fog band becomes broader. Marginal fog usually occurs only on plates along the edge of the emulsion coating during manufacture and not on the edges of plates formed by cutting the larger ones which are coated in the works. The defect appears to be due to the potassium bromide

wandering towards the centre, during the drying of the emulsion. Thus it does not generally occur on films as the margins of the film are cut away in course of manufacture.

The time of development necessary increases with the age of the material and the available contrast decreases. Colour sensitivity decreases unequally; the red sensitivity is lowered more rapidly than the blue sensitivity.

302. In tropical countries, the hot and humid atmosphere tends to produce a rapid change in photographic emulsions. Roll-films exported to these regions are usually wrapped singly in lead foil and packed in air-tight cartridges. It would be difficult to give this individual protection to flat sensitive materials, which are therefore often placed in wooden boxes, lined on the inside with zinc foil, and securely soldered; in this case the protection ceases immediately the box is opened. It should be pointed out that this type of packing, instead of protecting the plates, may accelerate the change if the soldering is done during very damp weather, owing to the fact that the packets have absorbed an appreciable quantity of moisture. Some film, wrapped in the usual light-tight packing, is sealed in airtight foil envelopes, then put in boxes; in this case waxed wrappers are not necessary. Well-made metal boxes sealed with adhesive tape are very serviceable both for the transport of unexposed emulsions and for the storage of opened packets and exposed plates awaiting development. A very efficient method of preservation is by means of a strong airtight wooden box (interior and lid lined with a layer of zinc), the lid of which is firmly held down by bolts or clasps on to a thick layer of indiarubber. Desiccation of the box may be obtained by using calcium chloride treated in the following manner (J. I. Crabtree, 1924): pieces of pumice or asbestos are impregnated with a saturated solution of calcium chloride, and then heated in an oven till dry. Excellent results can also be obtained with calcium sulphate dried at a temperature not exceeding 200°C. It has been noticed that too complete drying of cinematograph and roll-films increases the risk of formation of static markings (§ 247).

Well-dried newspapers may be used as a substitute, but they must be re-dried every time the box is opened.

303. Handling of Materials. The order of use of the materials of each different type should be decided by the age of the material; in this manner stale plates and films in stock are avoided.

If the boxes are opened neatly and the black paper wrappings kept, they may be used for packing and classifying the finished negatives or for re-packing the exposed but undeveloped plates and film. The instructions should also be kept for future reference, in case it should be necessary to look up any special directions for that particular type of emulsion.

It is preferable that opened packets should only be stored in the darkroom if they are to be used without delay; if not, they should be placed in stock, having first been secured with gummed paper, or at least with a strong rubber band. It is an advantage to seal up the box with a label indicating the number of unexposed plates or films and the date on which the box was opened.

In an opened packet do not allow the emulsion surface to be placed in contact with any paper, other than the original interleaving sheets. Although certain specially-prepared or treated papers, such as those used in roll-films, film packs, or as interleaving sheets, are without effect on the emulsion, it is often found that after prolonged contact with an ordinary paper, the structure of the paper appears on the image after development.

304. Loading Plate Holders. Plate holders or dark slides should always be loaded in a room illuminated only by light of suitable colour and intensity, as recommended by the manufacturer, for the particular emulsion being handled. It is desirable to practise filling the plate holders first in full daylight, using waste negatives for this purpose, and then, having become familiar with the operation, to get accustomed to working in complete darkness. When a darkroom is not available dark slides or plate holders may be loaded in full daylight by using a changing bag. This is a bag made of some opaque fabric provided with two sleeves, through which the arms are inserted. The ends of these sleeves are held tightly in place on the arms by elastic bands, and the sleeves of the coat are turned down over them to form light-tight shields. An opening, closed by two flaps of fabric held by snap-fasteners, enables

the operator to insert the plate holders, the box of plates, and an empty box for the exposed plates, when these are too large to be inserted through the sleeves of the changing bag. When absolutely necessary, and provided that a dark place can be found, plate holders may be loaded under an overcoat, the arms being inserted through the sleeves from the wrists.

Sensitive materials should always be held by the edges. The fingers should never come in contact with more than the minimum width around the edges of either surface of the material. Wherever the fingers touch the emulsion, even when they seem quite clean and dry, a minute quantity of greasy matter is deposited on the gelatine. This prevents the developer from penetrating the emulsion, and produces a light finger-mark on a dark ground in the developed image. Similar marks are sometimes found on a plate or film which has been packed with its sensitive surface in contact with the back of a plate on which there are finger-marks. For this reason, when plates are re-packed after exposure, they should always be placed face to face. Dark finger-marks on a light ground are the result of the emulsion having been touched by fingers impregnated with various chemicals, in particular sodium thiosulphate (hypo).

In order to use cut-film in plateholders it is possible, in small and medium sizes, to slip the film into a film holder securing it on three sides which will then fit into the plate holder. This arrangement does not ensure the necessary flatness with films of large and very large sizes. These may be held with the back in contact with a rigid support, e.g. glass or sheet metal coated with an adhesive varnish containing vinyl resins (M. Hagedorn and A. Jung, 1931) or rubber. If required, the film can be left on this support during development and further processing. The use of a blackened support can, in some measure, act as an antihalation protective.

Except in special cases, the sensitive surface of a plate or film should always be turned towards the outside when loading a dark slide. Dufaycolor and similar materials are, of course, exceptions, as are also plates intentionally reversed in the plate holder for the purpose of obtaining reversed negatives. In such cases when focusing it is necessary to adjust the camera extension to allow for the thickness of the glass.

Although plates are always packed in a uniform manner, uncertainty may occasionally arise with regard to which is the sensitive side.

In order to ascertain this, a corner may be touched cautiously, care being taken to touch the surface as near the edge as possible. The glass is smoother and feels colder than the emulsion. If still in doubt, moisten the thumb and first finger slightly and hold the corner of the plate between them. The sensitive emulsion will stick to the finger; the glass will not. In the case of materials with an antihalation backing, which has a gelatine base, the difference will not be so marked but the emulsion side will stick more firmly than the backing side. When using sheet film, the emulsion side can be identified by the notches which the manufacturer makes in one edge of the material. The emulsion side is facing the operator when the notch, or notches, can be felt on the right-hand side of the top edge with the longer dimension held vertical. These notches also indicate the type of emulsion by their number and position, but as different manufacturers' codes vary, the relevant maker's data sheet should be consulted.

Before loading is begun, the plate holders, which retain dust very easily, should be carefully cleaned.

The different types of plate holders vary considerably in the method of loading, so that in each case the instructions of the maker or the dealer should be consulted.

Often, when fitting a plate with sharp edges into a plate holder or metal dark slide, small pieces of glass are broken off. Loading should therefore never be carried out over the open box, or over plate holders which have already been loaded. When plate holders have been loaded, they should be protected from bright light and dust until used. The fact that *roll-film spools* may be loaded in daylight does not imply that it is advisable for this purpose to choose a well lighted place, still less a place where direct sunlight may reach the film. The paper wrapper should on no account be allowed to unroll loosely so that the light can penetrate into the sensitive surface. When loading film packs, care should be taken to avoid pressing the black paper slide or squeezing the pack from opposite sides, for, owing to the flexibility of the case, light may easily enter.

305. Dusting the Sensitive Surfaces. With very few exceptions, the emulsion surface of plates and films is perfectly clean when purchased, for every precaution has been taken to this end in the factory, where the struggle against dust is often carried to greater extremes than in many surgical operating theatres,

since only filtered air is allowed to enter the factory.

After development, however, a number of white spots (pinholes) are often found on the negative, each of which marks the shadow of a grain of dust which was present before exposure. In professional work these markings have to be carefully spotted out.

These dust particles are more frequently found on very fast plates, the surface of which is more mat than that of the slow emulsions and therefore much more liable to retain any dust which comes into contact with it.

The doubtful cleanliness of some darkrooms, the use of fluffy paper for packing plates, chips of varnish, the fragments of glass produced in the loading of the dark slide or plate holder, explain the presence of these dust particles, which are rarely found on roll-films.

Attempts are often made to prevent these pinholes from forming by dusting the face of the plate before its insertion into the dark slide or sheath. These precautions, however, often make matters worse, especially if a hair brush or a velvet pad, which has been left lying about the room and is consequently full of dust, is used for the dusting.

The most effective method for preventing pinholes is to clean the darkroom and the plate holders very frequently, preferably with a vacuum cleaner, and also to follow closely the instructions given above for the loading of the plates. Where it is not possible to get rid of dust in this way, then a brush should be used, but it should be kept in a smooth-walled box when not in use and should be frequently cleaned by shaking and washing in alcohol. For detaching the dust which has adhered to plates during the loading of a plate holder or varnished metal dark slide, it is often sufficient to rap the holders smartly on the table.

In any case, replace the slide of the holder very gently, holding the dark slide with the plate underneath, so that any dust on it is able to fall away.

306. Unloading the Dark Slides. If the films or plates are not developed immediately after removal from the dark slides, they should be replaced in their original wrappings with suitable spacers or interleaving sheets of paper. Remember that the use of all common papers, with or without writing or printing, is liable to cause various defects (§ 303). The boxes should be sealed and clearly marked to indicate exposed plates.

If, however, development is carried out in vertical tanks with hangers, the handling of the sensitive materials can be reduced to a minimum if they are transferred to the hangers on removal from the dark slides. The loaded hangers can then be stored in a suitable light-tight box pending development.

In tropical regions, particularly if films are being used, the sensitive materials should be dried before repacking in order to prevent regression (i.e. fading) of the latent image, a phenomenon caused by the simultaneous action of heat and moisture. For this purpose the sensitive materials (long rolls of film should be wound into loose spirals) should be placed in an air-tight box with suitable drying arrangements as mentioned earlier in this chapter. After leaving them for a day in this dry atmosphere the sensitive materials may then be repacked, and the packets, which have been dried also, are then enclosed in soldered or air-tight boxes.

When unloading darkslides or the sheaths of a changing-box, avoid any contact with the emulsion surface.

In some cases when the air was exceptionally dry, it was noted when unloading the sheaths of a changing-box that a bluish light occurred at the moment that the bare glass back of the plate parted from the markedly arched back of the sheath, the light being the brighter the more rapidly the plate was pulled out of its sheath. Starting from the edge where the electrical discharge began, these plates had a shaded fog extending for a distance of 4 cm. (J. Boillot, 1933).

307. Identification of Negatives. In all cases where a large number of negatives are dealt with, or where it is required to determine the effect of certain alterations in treatment on a number of negatives of the same subject, it is necessary to adopt an infallible scheme of identification.

The simplest method is to write a number with a soft pencil in one of the corners of the plate, taking care not to encroach on the picture area of the plate. Never use copying ink pencils, otherwise the inscriptions

may either become discoloured during the various treatments or may spread on to the image. If the inscription can be made during loading (where there are only a few negatives to identify) the pencil mark protects the emulsion from the action of light, so that after development the number appears light on a dark ground, even after the original pencil mark has been removed. If the inscription cannot be made until after the exposure, the number corresponding to the customer's order (in portrait studios and businesses catering for amateurs) or similar inscriptions should be made with a semi-hard pencil so as to scratch the gelatine.

Various arrangements have been devised which will give each negative a permanent or provisional number more or less automatically, viz. (1) in a portrait studio, a number plate or a slate, with the number corresponding to the customer's order written upon it in chalk, can be placed in such a position that the image will appear in one of the corners of the negative; (2) one of the fixed holding pieces in each dark slide may be replaced by a metal plate perforated with the required figures. In X-radiographs it is usual to place opaque (lead) letters in the path of the X-rays, so that the lettering appears light against the dark background.

Special clips for development may be obtained, the tops of which are made to receive a numbered card. In many developing and printing firms the small length of film which extends beyond the last exposure is used to record photographically the number of the order. The numbered receipt, made of very thin paper, is inserted, together with the end of the film, into a specially constructed printer, in which they are pressed tightly together by a shutter which automatically turns on the light used for the exposure as it is brought into position. The number may also be impressed on the film in greasy ink by means of a numbering machine. Finally, the method usually employed in cinematography could be employed, the films and order form being perforated with the required number by means of a machine similar to that used in banks for indicating the amount of a cheque.

CHAPTER XXIV

LIGHTING OF THE SUBJECT: DAYLIGHT: ARTIFICIAL LIGHT

308. Daylight. Daylight is not only of a very variable intensity, according to the geographical position, the season, time of day, and the atmospheric conditions, but its composition also varies over very wide limits, although it is always conventionally called "white light."

When referring to daylight, it is necessary to distinguish between direct sunlight and the light diffused by the blue or clouded sky.

On a clear day, the light consists almost exclusively of direct sunlight. A comparison of the intensity of illumination of a white surface exposed to direct sunlight and of a shadow thrown on this surface, in which case the shadow is illuminated only by the light diffused from the sky, shows that diffused light represents only about 5 per cent of the total light. This proportion increases as the sky becomes more clouded, until, when it is completely overcast, there is nothing but diffused light. Setting aside the effect of contrast, shadows are better lighted as the sky becomes less clear, that is, as the diffused light increases. In fact, the brightness of the sky at first increases with the cloudiness and, in the case of large sunlit cumulus, can be as much as eight times that of ordinary blue sky. If, however, the sky becomes so cloudy that rain is imminent, then the brightness diminishes, being approximately equal to that of blue sky.

309. Leaving aside for a moment the effect of atmospheric conditions, the intensity of sunlight depends essentially on the *height of the sun* above the horizon. Thus, in two widely separated places (a tropical and a temperate region), the light will have the same value at those times when the height of sun above the horizon is the same. Thus, at Algiers on 15th January or 1st December, at 9.20 a.m. or 2.40 p.m. (local time), the intensity of sunlight will be the same as in Paris on the same days at 11.30 a.m. and at 12.30 p.m., or on 15th June at 6.20 a.m. and 5.40 p.m., for in all these cases the sun is 20° above the horizon.

There is no evidence of any appreciable variation in the colour quality of daylight throughout the day (E. W. A. Selwyn and F. H. G. Pitt, 1938). But at the extreme ends of the day the transmission of the light through

the earth's atmosphere at low altitudes is liable to give rise to red sunrises and sunsets. To these may also be added the effect of an unusual amount of fog which often colours the sun to the same red hue. Apart from these and other peculiar atmospheric conditions the quality remains fairly constant. Measurements have been made in America by G. G. Abbot, (1923) and I. G. Priest (1920), on which has been based the work by R. Davis and K. S. Gibson (1931), of the National Bureau of Standards. More recently measurements have been reported by A. H. Taylor and G. P. Kerr (1941), in which variations in the spectral quality of daylight between the wavelengths of 400 and 700 μ have been measured. So far no one in England has published any similar work but it is safe to say that no great variation would be expected.

As has already been said, the outer atmosphere scatters appreciable quantities of blue sunlight on to the earth. Therefore one would expect light from the blue of the sky which falls into shadows thrown by the sun to cause the shadows to be predominantly blue, and this is quite noticeable when colour photographs are taken in the shadow of large buildings. Normally any position on the earth's surface with an unrestricted view of the sky receives radiation from all angles. When cloud or mist intervenes the light becomes diffused but as the lighting is not obstructed locally in any way there is no change in quality of the light reaching the earth's surface.

There have been tendencies to regard the blueness of daylight as a variable quantity and in fact this was noticeable on non-colour-sensitized plates which are sensitive only to blue light. On panchromatic plates, however, which are sensitive to the whole of the spectrum any variations which might occur would be considerably masked.

The intensity of illumination on the earth's surface, i.e. perpendicular to the direction of the sun, is about 10,000 ft-candles at its zenith on the equator and about 2,000 ft-candles at its zenith of latitude 50°. Normally in Europe the intensity of light on days when photography is popular, i.e. in fine weather, is between 200 and 1,000 ft-candles. As the weather deteriorates

and the sky becomes overcast with rain clouds the illumination may drop as low as 10 ft-candles. There is also a very large and rapid fall in illumination after dark for even the brightest moonlight, which is merely reflected sunlight, can only rise to about 0.05 ft-candles. In its early and late phases moonlight is sufficiently bright to allow certain objects to be recognised at 0.001 ft-candles. Below this level we have the illumination due to starlight or to the moon covered by clouds. The lower limit of human night vision lies at about 0.00001 ft-candles.

Normal room lighting by artificial sources

offered by the variation in direction of the lighting during the passage of the sun across the sky.

In portrait and still-life photography, various means of control are available. A detailed description of the arrangements in a portrait studio can be readily obtained.¹ It may be added that at the time photography was first practised, when exposures, even in the most favourable cases, were counted in minutes, as much light as possible was admitted into the studios, with entire disregard of light and shade, by constructing them entirely of glass. Owing to the considerable progress which has been made in

Source of light	Proportion per cent of the radiations			Relative efficiency towards emulsions		
	Red	Green	Blue- violet	Ordinary	Ortho- chromatic	Pan- chromatic
Sun	33.3	33.3	33.3	100	100	100
Petrol flame	80	18	2	18	28	42
Acetylene flame	62	32	6	30	44	52
Incandescent gas mantle	54	38	8	—	—	—
Low voltage arc, ordinary carbon	50	32	18	125	110	105
High " " (enclosed)	60	25	15	175	175	165
White flame carbon arc	40	35	25	255	235	215
Electric lamps { Carbon filament	65	30	5	24	33	43
{ Tungsten vacuum	61	32	7	35	43	52
{ Tungsten gas-filled	50	30	20	60	65	73
Mercury arc, glass tubes	nil	10	90	310	350	270

probably lies between 1 and 50 ft-candles when reasonably large areas are being illuminated. Special circumstances, however, often require a much greater level of intensity for short periods. The methods which are used to obtain such conditions are described later. It is worth noting at this point, however, that as far as taking a photograph is concerned, variations in intensity cannot simply be compensated for by increasing the time of exposure. If such compensation were possible, it would indicate a reciprocity of time and intensity for the photographic emulsion, whereas in fact the majority of the high-speed photographic emulsions show a reciprocity of time and intensity over only a limited range. Below a certain level of intensity there is a failure of the reciprocity law and compensation must be made for this loss. Where the exposure time is longer than a few seconds it may be necessary to increase the exposure by as much as 50 per cent for each stop difference in intensity (§ 208).

310. In landscape photography the lighting depends on the position of the sun and therefore the photographer has only the possibilities

the manufacture of sensitive materials and photographic lenses, such studios are now obsolete.

311. **Artificial Light Sources.** The three factors to be considered in an artificial lighting installation for photography are quantity, colour and the degree of diffusion. There is also the economic side of the use of artificial light to be considered, the cost of the equipment, lamp replacements and cost of electricity used.

Colour depends essentially on the nature of the illuminant. Compared with sunlight there is always a predominance in artificial (tungsten) light of infra-red and red, the extent of the spectrum and its intensity in blue-violet and especially in ultra-violet being all the less, as the temperature of the incandescent body becomes lower. In order to give a higher effective speed, some panchromatic materials have been made in the past with extra red sensitivity. This is a more effective use of the larger proportion of red light given out by incandescent lamps.

The table on this page, the data of which have

¹ Herbert Lambert, *Studio Portrait Lighting* (Sir Isaac Pitman & Sons, Ltd., 1936).

been taken from various papers by Hubl, Ives, Jones, Hodgson, and Huse (1913 to 1916), shows the approximate compositions of various light-sources relative to sunlight, which is taken as the standard for comparison (on the assumption that sunlight may be divided into three equal parts of red, green, and blue-violet, the partial intensities in each case being brought to a total of 100). Their relative efficiency towards three types of sensitive emulsions is also given, and for this purpose the value of 100 is arbitrary assigned to sunlight, the efficiency of the other sources being measured *for equal visual intensity*. No account has been taken of ultra-violet radiations, even in the region transmitted by glass.

Lamps usually radiate light in all directions, so that their efficiency is increased by reflectors bringing back to the subject the light emitted in other directions. When high-intensity lamps are used for living subjects they must be fitted with diffusers preventing dazzle. From these various points of view the efficiency of a lamp can be of very different values according to the apparatus in which it is used.

312. Arc Lamps. The arc lamp was for some time the only luminous source from which high intensities could be obtained. When used for the lighting of photographic subjects this source introduces the defect which is common to all point-sources, the shadows are sharp, and the rendering is harsh. Diffusers over the lamps will overcome this disadvantage. Alternatively extra lights near the camera soften shadows effectively.

Since the introduction of mercury arcs, and the great improvements which have been made in the manufacture of incandescent lamps, arc lamps are much less used in general photography but still find employment in motion picture and process studios. As these applications lie outside the scope of this book, we shall not attempt to describe the various types of arc lamps.

313. Incandescent Lamps. The first notable use of the incandescent lamp for the illumination of sitters and originals to be photographed dates from 1913, when I. Langmuir first made lamps with a tungsten filament enclosed in an atmosphere of inert gas. In these gas-filled lamps the pressure exerted by the gas retards the volatilization of the metal, making it possible for very high temperatures (exceeding 2,800°K) to be reached at which the light emitted approximates very closely in composition to

that of an arc lamp. Studio lamps of from 1 to 10 kW are in common use, and the life of these lamps is about 100 hours at 3,100°K.

The luminous intensity and photographic efficiency of a given lamp increase as the filament is heated to a higher temperature, which is effected by running the lamp at a higher voltage. Such overrunning is limited by the increasingly rapid volatilization of the incandescent metal, causing rupture at the weakest part of the filament.

The rating adopted for ordinary lamps for domestic and public lighting gives them an average life of 1,000 hours (which may, however, be considerably shortened by variations in the supply voltage. Photoflood lamps operating at 3,450°K, have a short life of two or six hours depending on the type. It is good practice to use these lamps in twos, in series, up to the moment of exposure, when by suitable wiring they can be switched into a normal parallel connexion. This will prolong the life of the lamps at no loss of brightness for the actual exposure.

The two-hour type of Photoflood probably represents the greatest practical amount of overrunning, but several types of photographic lamp are also made which are overrun rather less, with a consequent increase in life, and lower efficiency. The table below lists these lamps together with some others in common use—

Normal use	Wattage	Lumens/ watt	Colour Temperature	Useful life
			(°K)	(hours)
General lighting	40	10.7	2750	1000
General lighting	100	15.3	2865	1000
General lighting	500	19.6	2960	1000
General lighting	1000	20.7	2990	1000
Motion pictures	1000	24.5	3040	250
Motion pictures	2000	27.5	3100	100
Projectors (Low voltage type)	500	26.3	3190	100
Projectors (110 V)	1000	32.5	3360	15
Photography	275	35.5	3450	2
Photography	500	34.0	3425	6
Photography	1000	33.0	3400	10

Owing to voltage fluctuations at different hours of the day which influence colour temperature it is a good idea to have a voltmeter connected in the lamp circuit. Fig. 24.1 shows the general effects on the performance of tungsten filament lamps caused by variation in the supply voltage.

In an installation where all the lamps are not used at the same time, they should be frequently changed round to prevent those

which are used most from being worn out. Some high-power lamps contain a few grains of tungsten which, when shaken, clean the interior surface of the bulb. The efficiency of lamps is considerably lowered by accumulated dust on the bulbs, reflectors, and diffusers.

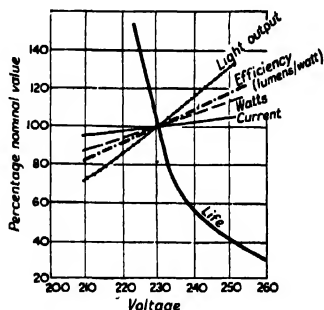


FIG. 24.1. LIGHT OUTPUT, EFFICIENCY, CURRENT CONSUMPTION AND LIFE OF A 230-V TUNGSTEN LAMP AS FUNCTIONS OF THE SUPPLY VOLTAGE

As will be seen from Fig 24.1 the intensity, and efficiency of a lamp in lumens per watt vary with the current and voltage of the supply. These are never very constant and for climatic and other reasons they develop quite big variations. A voltmeter will at least give a warning of such variations even if they are not controllable by a series resistance, etc. The useful light output, of course, varies with the colour temperature and depends on the sensitization of the photographic emulsion. It is necessary, in fact essential, to maintain the colour temperature constant when colour film is being exposed. For black-and-white emulsions, particularly panchromatic, it is not usually possible to notice changes in colour temperature unless there are differences of several hundred degrees.

Reduction of voltage deliberately as a means of controlling the photographic intensity and exposure has been investigated by C. Tuttle (1937), who determined the relationship—

$A = (K - R)/m$ where A is the actinic intensity, K and m are constants of the lamp, about 2.3 and 11.5 respectively for a 500-watt 110-volt lamp and R is the series resistance.

It is only necessary to determine the actual ratio of brightness at two values of R in order to calculate the constants K and m which can then be used in the equation to calculate other values of A .

314. With the increasing use of colour film,

the professional photographer finds it essential to have close control over the colour temperature of the lamps. Reputable lamp manufacturers can be relied upon to produce lamps within $\pm 50^\circ\text{K}$ of the value for which the colour film has been designed. This value is $3,150^\circ\text{K}$ for the professional types of film to be used in the studio, and about $3,450^\circ\text{K}$ for amateur use with photoflood lamps, etc. Age and supply voltage variations affect the colour temperature of these lamps which may in turn be compensated for by a colour-filter over individual lamps or a filter over the camera lens (§ 5).

315. **Mercury-vapour Lamps.** These lamps were invented in 1901 by P. C. Hewitt, and could only be used at first with direct current; they could not be started from a distance, because they had to be tilted in order to strike the arc. Owing to the many improvements which have been made in their manufacture, special lamps can now be supplied, which run on alternating current and are lighted merely by closing a switch.

The light from a mercury-discharge lamp is almost entirely from spectral emission of yellow, green, blue, and violet lines. The complete

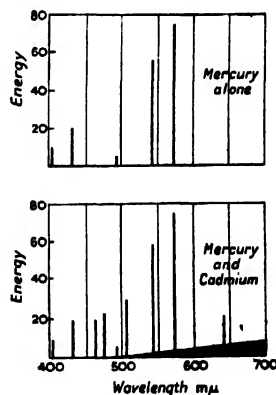


FIG. 24.2. SPECTRA OF A MERCURY AND A MERCURY-CADMIUM DISCHARGE LAMP

absence of red light is a great handicap for faithful reproduction in either monochrome or colour.

During the last ten years (H. K. Bourne, 1948) there have been great advances in the re-design of discharge sources to include cadmium in the discharge and now it seems that these lamps may yet rival the improved high-intensity

carbon arc lamps and tungsten lamps with advantages of efficiency and economy.

The Cooper-Hewitt lamp was rated at 250 watts. It was one inch wide and four feet long with a mercury pool at one end and an electrode chamber at the other. The arc loading was therefore about two watts per cm. The bulb temperature was only 100°C with a pressure of 1 mm of mercury and an arc voltage of 70 volts. It was very rich in ultra-violet light and had a luminous efficiency of 15 lumens per watt. Higher pressure produced higher efficiencies. From experiments on these lamps it became obvious that high pressures, high temperatures, and high arc loading would give even higher efficiencies. The difficulties were to produce glasses and seals which would withstand the strain of the conditions imposed. The type MA high-pressure mercury vapour lamp, which was the outcome of the early Cooper-Hewitt tubes, was made to have an operating pressure of 1 atmosphere (760 mm mercury) a temperature of at least 360°C and an efficiency of 40 to 60 lumens per watt. The arc loading was now 20-30 watts per cm and the voltage gradient between 5 and 10 volts per cm. The life of the lamp was about 3,000 hours. A hard glass tube was used.

To make lamps of higher efficiency it was necessary to develop tubes which would work at higher pressures and temperatures.

The maximum possible loading of air-cooled mercury arcs is about 50 watts per cm. Increased loading needs extra cooling by forced air draughts or water. The arc is contained in a quartz tube into which are sealed tungsten wire and glass beads. This tube is then mounted in a water jacket consisting of two concentric glass cylinders one of which is supported at one end only. The velocity of water is necessarily high to avoid boiling and the clearance is therefore made small. The water flow is about 3/4 gal per min (3.5 litres per min). The arc loading of the 1,000-watt lamps is about 400 watts per cm, and the pressure is about 75 atmospheres. The life is usually some 100 hours, with a decay of the order of 30 per cent in brightness. The horizontal brightness is 3,000 c.p. and the width is 1 mm with a brightness of 25,000 candles/cm². The length of the arc is 25 mm. The red content of the light emitted by the lamp is about 6 per cent.

316. Fluorescent Lamps. The lack of red in the line spectra of mercury has been compensated for by various methods; one of these is the use

of phosphorescent powders. The well-known domestic and industrial fluorescent lamps consist of a tube 5 ft long and about 1½ in. in diameter in which a low pressure discharge is formed consuming 80 watts. The inner walls are coated with mixtures of phosphors to transform the energy from the mercury resonance line at 254 mμ into visible light. The visible blue-green and yellow mercury lines are still transmitted through the powder and glass envelope. The great advantage of these lamps is that their colour temperature is constant.

The brightness is dependent on supply voltage, but the colour temperature is dependent only on the phosphors. There is no appreciable change in colour with life. Over the first hundred hours there is a drop in efficiency to the rated value. The operating temperature is 40°C , and variations in this, particularly if it is exceptionally cold, will affect the efficiency. This latter effect is due to the low pressure and arc loading, which are sensitive to changes in conducted heat effects.

In Great Britain there are two types of 80-watt tube. The "Daylight" type has a colour temperature of about 4,800°K (almost C. I. E. Illuminant B), and the "Warm-White" type is rather on the magenta side of a colour temperature of 3,700°K. The efficiency of these lamps is between 35 and 45 lumens per watt depending on colour and wattage.

317. Flashbulbs. There has always been a need for an easily carried source of light, of sufficient power for reasonably short exposures. In the earlier days of photography this need was filled by magnesium metal which was used either alone in the form of ribbon, or as a powder combined with potassium perchlorate. Flash-powders containing other metals such as cerium, thorium, and zirconium have also been used, but all of them suffered from the grave disadvantage that the combustion of these inflammable materials was dangerous and very likely to produce considerable amounts of smoke and chemical dust.

It was a logical step to attempt to enclose the burning material so as to overcome these disadvantages, and a simple type of lamp containing a flash powder was designed in 1925 by P. Vierkotter. In 1929 J. B. Ostermeier replaced the powder in a bulb by aluminium foil in oxygen at a reduced pressure (1/4 atmosphere). This lamp set the style for manufacturers for several years and further types with minor variations (such as wire in place of foil) to suit

particular needs, appeared. The most recent type of lamp which is generally called the Speed Midget or Speed Flash type contains no foil or wire, but uses a paste coated on the lead-in wires. This enables a much smaller bulb to be used.

318. The Source of Power. Whether the flash is produced by foil, wire, or paste, the material is ignited from a dry cell of the type used in pocket torches. Some of the larger bulbs can, however, be fired from the mains supply if so desired, and if intended for this will have fuses incorporated in the cap. However, since one of the principal advantages of flashbulbs is the independence of mains supply which they give the photographer, the dry cell is a more generally used source of current. The voltage generally needed to fire a flash bulb is of the order of 3, and two unit cells of the type known as U.2 are most commonly used (Type D in the U.S.A.). The necessary current is about 0.3 amperes for each lamp, and the ability of a dry cell to deliver this current depends on its freshness and the reliability of the maker. The variation in current which a cell can supply is of some importance since it can affect the exact timing of the flash. It is as well to ensure that the cells are fresh enough to give satisfactory results by testing them with an ammeter. On connexion directly across the cell the ammeter should give a reading of *at least* 2 amperes. This reading will drop very rapidly if the ammeter is left connected, since the meter represents almost a dead short circuit, and so the meter should be connected only for a few seconds. So long as the instantaneous current reaches the above value the cell can be considered satisfactory.

The current provided by the cells is used, when the circuit is completed, to heat a small filament in the bulb. This filament is of a similar type to that in an ordinary torch bulb. The filament ignites a combustible paste coated round it, which in turn ignites the foil or wire with which the bulb is filled.

A number of modern flash guns comprise an electric condenser, which is charged by a relatively weak battery and discharged through the bulb on firing. These "capacitor flash guns" are more reliable since even a battery in poor condition, which may be unable to fire a bulb, is capable of charging a battery.

319. Bulb Characteristics. The exact duration of the flash, and the time it takes to build up to a maximum intensity depends on the filling. The total effective duration of the flash of a

Speed Midget bulb is about $1/200$ sec. (more conveniently stated as 5 milliseconds). The delay between the time the circuit to the battery is made and when the amount of light from the bulb reaches an effective quantity is also, with this type of bulb, 5 milliseconds.

When a long flash is needed, for example

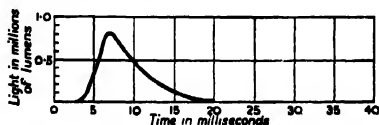


FIG. 24.3. TIME/LIGHT-OUTPUT CURVE OF MIDGET PASTE-TYPE FLASH BULB (G.F.C. SM.)

when using a camera with a focal-plane shutter (§ 142) a foil-filled bulb is generally used. For general use, flashbulbs are filled with aluminium wire or shredded foil which has similar characteristics.

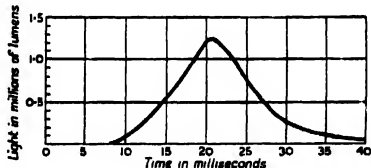
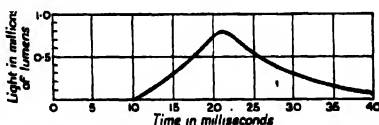


FIG. 24.4. TIME/LIGHT-OUTPUT CURVE OF A MIDGET SHREDDED FOIL-FILLED FLASH BULB (B.T.H. No. 5.)

Information on the amount of light given out and the total duration of the flash is most conveniently shown in the form of a graph. The usual form which this takes is shown in Figs. 24.3 to 24.6 in which the time from



* FIG. 24.5. TIME/LIGHT-OUTPUT CURVE OF A MIDGET WIRE-FILLED FLASH BULB (Philips P.F. 14.)

completion of the circuit (measured in milliseconds) is plotted horizontally and the light output (in millions of lumens) is plotted vertically. The four graphs have been chosen to show the widely differing characteristics of four representative bulbs. Fig. 24.3 shows the short delay, brief period of brightness, and small light output of the paste-type midget bulb. Two bulbs suitable for general use are shown at

Figs. 24.4 and 24.5. The first of these is a shredded-foil type, the second a wire-filled. Fig. 24.6 shows the extended peak needed for a bulb designed to be used with a focal-plane shutter.

The amount of light given by a flashbulb is usually given in *lumens* (§ 12), and the product of this figure and the total time of the flash in seconds is frequently quoted by the

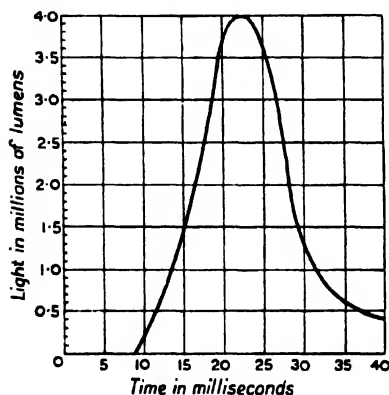


FIG 24.6. TIME/LIGHT-OUTPUT CURVE OF LARGE SHREDDED FOIL-FILLED FLASH BULB

(G.E.C. No. 22)

manufacturers as the *total light output in lumen-seconds*. These figures enable two bulbs to be compared directly only if they are to be used with the camera shutter open for the whole period of the flash.

Another figure which is sometimes quoted is the *duration above half-peak* of the flash. This represents the useful exposure time if the flash is used with camera shutter open.

The delay is for the most part standardized at 20 milliseconds with the exception of midgem types and some of the very large bulbs.

A useful application of the *inverse square law* (§ 11) combined with the fact that the brightness of the image varies inversely as the square of the *f* number (§ 89) makes the estimating of correct exposure with flashbulbs a simple matter. Precision manufacture of bulbs results in an accurate control of the amount of light which any bulb will give and it is sufficient and satisfactory to assign a particular type of bulb a *Guide Number*. Manufacturers issue a table of guide numbers for their bulbs for various film speeds and shutter speeds. The correct aperture to

give correctly exposed negatives is found by dividing the guide number by the lamp-to-subject distance. It is preferable for the photographer to check and perhaps modify, by means of a few tests, the guide numbers of the bulbs he will use, when used with his own equipment. Individual reflectors vary in their efficiency as do shutters, but once one guide number has been checked, all others will be in proportion and no further tests need be made.

320. Synchronizers. Paste-type bulbs give an equivalent exposure time of $1/200$ sec, and have a delay (5 millisec) which corresponds to the opening time of most inter-lens shutters. These bulbs are designed to be used mainly on cheap cameras which have shutters fitted with simple electrical contacts. (This does not, of course, prevent their use with any camera with the shutter set for a brief time exposure.) The short total time of the flash enables any normal movement to be satisfactorily stopped, whilst the amount of light they give is sufficient to enable a small aperture to be used, and any other lighting will not record.

When it is necessary to use an exposure time of $1/25$ sec or shorter with normal wire or foil filled bulbs some sort of a *synchronizer* is needed to ensure the opening of the shutter at the same time as the peak intensity of the lamp.

The synchronizers available can be divided into three types—

- (i) Simultaneous-release synchronizers.
- (ii) Mechanical synchronizers.
- (iii) Electro-magnetic synchronizers.

321. Simultaneous-release Synchronizers. These are designed for paste-type bulbs, and enable them to be used on any camera, even if it has not an internally synchronized shutter. As their name suggests they make the electrical contact for the bulb at the same instant as the shutter is released. In essence a simultaneous-release synchronizer is a cable release containing a switch to complete the flashbulb circuit. They can be simply synchronized without waste of bulbs, but can only be used with shutter speeds of $1/25$ or $1/50$ sec.

322. Mechanical Synchronizers. This type replaces the finger of the photographer on the shutter release, by the power of a spring. There are several variations of this type of synchronizer, but essentially they are similar, in that the spring is wound by hand and held by the release. When the release is pressed the spring operates the shutter release and at some point in its

travel makes the contact for the flashbulb. The point at which the contact is made is generally adjustable to enable synchronization to be set at will.

Synchronizers of this type enable the photographer to use high shutter speeds and ensure that the shutter is catching the peak of the bulb.

323. Electro-magnetic Synchronizers. An electro-magnet connected in series with the battery and the flashbulb is used in this type of synchronizer. The magnet is firmly mounted on the lens board of the camera and when energized operates the shutter release. The magnet is adjustable for synchronization. The only disadvantage of this system is the fact that the magnet will need quite a large current to operate efficiently. The minimum number of unit cells (U.2 or Type D.) which can be used for this type of equipment is three, connected in parallel, since an instantaneous current of about 7 amperes is needed.

324. Synchronizer Adjustment. All manufacturers of synchronizers send them correctly adjusted but at times it may be necessary to readjust the mechanism. Without the proper equipment this is a difficult job and one not to be lightly undertaken. In the U.S.A. several manufacturers make accessories which simplify the synchronization of a flashgun, such as the Synchroscope made by Kalart, which needs the expenditure of no film or bulbs.

Perhaps the most direct way to check synchronization, although it is somewhat expensive in bulbs, is to photograph the bulb itself, either in a mirror, or on an extension cord. This can be done on film, using a very deep filter, or on bromide paper placed in the camera. In either case a small stop and a high shutter speed must be used if the negatives are not to be hopelessly over-exposed.

If the synchronizer is properly adjusted the negative should show the bulb completely filled with burning material.

With the aid of photo-electric cells and either a cathode ray oscilloscope or a ballistic galvanometer it is possible to check the output of a flashbulb, measure the delay and check the synchronization (J. A. M. van Liempt and J. A. de Vriena 1935-7). However, these methods belong more to the laboratory or factory than to the darkroom.

325. Electronic Flash. Flashbulbs have recently (1942-46) been introduced which are capable of repeated flashing. The principle employed in these so called *electronic speed flash*

tubes is different from that used in ordinary flashbulbs.

When a glass or quartz tube is exhausted to a near vacuum and small quantities of rare gases such as krypton or xenon introduced, it is possible to cause a glow discharge between two electrodes at the ends of the tube. This phenomenon has already been explained (§ 9) but in the case of electronic flash tubes the voltage across the two electrodes is high and of short duration. This produces a very brief ($1/5,000$ to $1/10,000$ sec) flash which is of high intensity. The bulb itself consists of a spiral tube of quartz in which the flash proper takes place. The tube is contained within an outer glass envelope of similar shape to a small radio tube. The loading of the tube makes it essential that quartz be used, and even so, were the tube to be used continuously instead of for repeated short flashes, its life would be of the order of half a second. Normally used the tube is good for some 5,000 or more flashes. The colour of the light given by these tubes, as would be expected, is dependent on the gases used, and in commercial tubes approximates very well to daylight. Experimental flash tubes with suitable electric sets have been made to give exposure times as short as $1 \mu\text{sec}$ ($1/1,000,000$ sec) or to give rapidly repeating flashes for stroboscopic work (Edgerton, 1931).

326. The Light Output. The amount of light given by an electronic flash tube is not quoted in the same way as that given for normal flashbulbs, but in terms of the electrical power expended in producing the flash. This is usually given in England in *joules* but in the U.S.A. in *watt-seconds*. The two units are equal and interchangeable. An average tube is rated at 100 joules, but some portable outfits are rated at 60 joules, and there are studio models in use rated at 500 and 1,000 joules.

327. Power Supply. The voltage needed to produce the glow discharge in these flash tubes is of the order of 2,000 and special power packs are required to provide this. For portable outfits the original voltage is provided by a small 6-volt accumulator (a dry battery model is now (1950) on the market in England). The voltage from this source is applied to the primary of a transformer with a make-and-break coil in series, since a transformer will only work with an alternating current or interrupted direct current.

The transformer provides the necessary high voltage, which must be again converted to

direct current by a rectifier, to charge a condenser. The condenser stores the energy provided by the battery and other components of the circuit until the synchronizer (which may be of simple mechanical design) completes the circuit to the tube.

The design of a studio outfit is somewhat simpler since a supply of alternating current is usually available which renders the large capacity accumulator and make-and-break circuit unnecessary.

From the above description it will be seen that the power pack is necessarily rather bulky (although much has been done to make the weight of portable outfits reasonable), and expensive. The high voltages used render it essential that the pack and all leads be well insulated. The power pack should not be investigated by the unwary, since the condenser is capable of producing serious electric shock even some time after charging and even after it has lost the major part of its charge to the flash tube.

328. Electronic Flash in Practice. The very short time of the electronic flash makes it an invaluable light source for many types of work

and in general this type of lamp can be used for any purpose for which the normal flashbulb is used. The advantage of repeated flashes from one bulb, and the consequent saving on the cost of wire- or foil-filled bulbs is somewhat offset by the initial high cost of both tubes and power pack. It should be realized also that the total light output of the tubes used in portable outfits at least (about 10,000 lumen-seconds) is less than most wire- and foil-filled flash bulbs, but it is at least twice as much as the paste type. However, the studio type electronic flash sets provide enough light for excellent colour photographs to be made on the materials at present available, with exposure times so short as to be impossible by any other method.

Owing to reciprocity law failure (§ 205) negatives exposed by electronic flash tubes tend to lack contrast, and so it is advisable to prolong the development. One well-known manufacturer recommends an increase in time of development of 50 per cent above normal. This, of course, leads to an increase in the level of fog, and it may be preferable to use a negative material of higher contrast.

CHAPTER XXV

FOCUSING OF THE IMAGE AND THE POSITION OF THE SUBJECT ON THE PLATE

329. Focusing. In all cameras fitted with a ground-glass screen, the focusing will be done by visual examination whenever a fixed support is available. The image formed by the lens on the ground glass is examined, while both the distance of the lens from the screen and the aperture are varied until the image is of the desired quality. It is worth bearing in mind that with lenses possessing spherical aberration, a variation in the size of the aperture causes a displacement of the position of best focus.

A plastic effect is sometimes seen in the image formed on the ground glass by a lens the effective diameter of which approximates to the separation between the eyes. This is explained by the fact that the light is diffused by the ground glass with a maximum intensity in a direction corresponding to that of the incident beam, so that each eye sees the image formed by a different marginal part of the lens (§ 61). The position of sharp focus obtained visually has to be corrected when using non-achromatic lenses (§ 100), or for infra-red photography (§ 237).

If the ground glass is not too coarse, the sharpness can be judged much more easily with the help of a focusing magnifier (magnification of from 2 to 4 times), which is held against the screen in a sliding mount. This allows the lens to be set so as to give the best possible definition of the ground glass, or of any engraved or pencilled marks on its surface.

With the ordinary type of focusing magnifier the edges of the field cannot be examined at the oblique incidence necessary to obtain a well illuminated image. This difficulty can often be overcome by cutting away an oblique section of the tube of the magnifier, so that the lens can then be placed normally or obliquely against the glass, as necessary.

When using a camera of the type in which the moving part can be locked after focusing by means of a nut concentric with the knurled head controlling the rack-extension, it is always advisable to make sure that the focus has not been accidentally altered by tightening the lock-nut.

It will be found that the eyes will accommodate most comfortably while focusing a dimly-lighted subject, if the well-illuminated parts are

examined first, leaving the darkest areas to the end, after inspecting the portions of medium brightness.

If the subject is too dark to permit the image to be examined, good definition may be successfully obtained by focusing on the flame of a candle or lamp placed near to the chief parts of the subject, removing the bull's eye lens when using a pocket torch.

Hand cameras not equipped with ground-glass screens are focused directly by means of a coupled range-finder (§ 174) or, after the distance of the subject from the lens has been either judged or measured, by means of a distance scale (§ 87) or by the use of supplementary lenses (§ 117).

In all cases it is necessary to bear in mind the rules which have already been given dealing with the depth of field and the best distribution of sharpness between two given points (§§ 76 to 85).

When copying flat originals or prints by means of a suitably equipped apparatus (§§ 150 to 152), sharp focus and size of image are obtained by using the scales provided. It is only necessary to verify finally that no error has been made during these operations by an examination of the ground-glass screen.

330. Fine Focusing. On examination of the image formed on ground glass by means of a lens of low magnification, the eye receives simultaneously the diffuse light from the ground-glass screen and the light which is directly transmitted without scattering, the intensity of the latter being, of course, reduced by comparison with an image transmitted by a piece of clear glass. For a lens of aperture around $f/4.5$, the intensities of the scattered and directly transmitted images are approximately equal. One thus views simultaneously a material image formed on the screen and an aerial image, which may be situated either in front or behind the screen, according to the uncertainty of focusing. The existence of these two images makes exact focusing difficult. This difficulty can be overcome by the use of very thinly flashed opal glass instead of ground glass. It is as a rule necessary to reduce the thickness of the opal flashing by grinding until the filament of a

projection lamp 15 ft away from the glass held at arm's length just becomes visible. Opal focusing screens can naturally be prepared in small dimensions only. Their grain is much finer than that of ordinary ground-glass screens, and thus a lens of magnification up to 10 times may be used (E. W. H. Selwyn, 1943).

When it is necessary to obtain very precise focusing (scientific work, or tests for making a focusing scale), it is well to replace the ordinary method of *judging* the point of maximum sharpness by a *coincidence* method known as *parallax focusing*. For this purpose the ground-glass screen should be rendered transparent in one or two conveniently placed areas (centre and edges of field), either by protection during the grinding or by covering the desired areas with pieces of very thin glass (microscope cover slips) cemented with canada balsam. A cross should be scratched on the side of the screen facing the lens, or marked out with a hard pencil on the area to be covered.

After the image has been focused as sharply as possible by examining the ground part of the screen, a magnifying lens, adjusted to give a sharp image of the cross, is applied to the transparent area. It is now possible to see at the same time both the image of the subject and the cross in the plane of the screen. If the image is formed accurately in this plane, any displacement of the eye, either upwards or downwards, or to right or left behind the lens, will not alter the position of the cross relatively to the image. If, however, the image is out of focus, the direction of the displacement will indicate whether it is necessary to lengthen or shorten the camera extension. The extension is too long if the cross is displaced relative to the image in the same direction as the eye is moved. If the cross moves below the image as the eye is raised, the extension is too short.

331. Soft Focus. Perfectly sharp definition is an essential quality when dealing with certain scientific, legal, or commercial requirements, but may completely spoil an artistic photograph in which it is desired to suggest the impression conveyed by a subject but not to reproduce faithfully its finest details.

A photograph is not necessarily artistic, however, because the focus has been softened. On the other hand, a rigorously sharp picture, in which details ordinarily imperceptible to the eye without close examination are easily discerned, can never create an artistic effect, whatever other merits it may possess.

With artistic pictures, the focusing is always much more difficult to judge, for the degree and distribution of the softening demands not only a certain aesthetic taste and knowledge of psychology but also a full acquaintance with the various methods available for the production of pleasing soft effects.

The degree of softness will, in any one instance, obviously depend on a large number of factors, more specifically on the size of the picture, on the subject, and on the artistic education of the public to whom the work is to be presented. It is evident that outlines may be made much more diffused if the picture, owing to its size, is to be viewed from a distance. A portrait of a child or of a young woman can be treated with a certain amount of freedom, while that of an old man is often better rendered with a lesser degree of diffusion. And then, again, the uneducated will approve only with difficulty of a soft-focus portrait, which they will consider to have been bungled, whereas they will accept a photograph with softened outlines without any tendency to hardness. On the other hand, a photograph with very much softened outlines is much more pleasing to the cultivated taste, unless the effect has been exaggerated to a degree which is considered suitable only in studies executed for decorative purposes.

The method which most naturally suggests itself for the avoidance of the extreme sharpness afforded by the modern technically perfect lenses, such as the anastigmats, is to deviate more or less from the normal position of sharp focus. This method, however, invariably results in distinctly unpleasant portraits, in which the sharp definition, though absent from the main subject, appears in some minor part, either in front or behind the main subject, where it is least wanted.

An attractive portrait which is neither too sharp nor too soft can usually only be obtained by a combination of two images, one of which is perfectly sharp but of subdued intensity, while the other has softened outlines and is used to obtain the desired effect.

Many different methods may be used to obtain this combination, either from a single negative, by double printing from a single sharp negative, or by taking a print from a combination of two negatives taken at the same time. Fig. 25.1 shows in diagram form the appearance of a line in the principal cases considered.

Various optical methods are available which allow a negative with softened outlines to be

obtained directly, by arranging for certain rays of light to form a sharp image, the rest forming an out-of-focus image.

For landscape or still-life photography, the following method has been suggested by E. Genet (1923). The camera is first focused on a point considerably in front of the subject, and the lens is then stopped down until sharp focus is obtained. Half the requisite exposure is then given, after which the aperture is opened to an

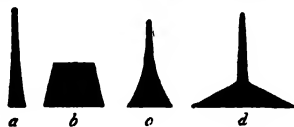


FIG 25.1. DISTRIBUTION OF DENSITY IN LINES OF VARIOUS IMAGES

(a) Sharp image. (b) Out of focus. (c) Softness produced by anachromatic lenses. (d) Superposition of a sharp and diffuse image.

intermediate position and finally to full extent. At each of these latter positions an exposure is given equivalent to a quarter of those necessary at the apertures used.

We have already mentioned the use of diffusing screens (§ 126), which transmit a sharp image through the central part and a soft image through the outer part. Thus it is a common practice, especially in enlarging, to place in front of the lens a piece of stretched fabric, which by diffraction introduces a certain softness into the print. The softness increases with the closeness of the weave of the fabric; the more the threads diffuse the light the less the contrast.

The most convenient method of obtaining a negative with soft outlines is that of using a specially designed lens which has been imperfectly corrected for spherical or chromatic aberrations. The resultant image is then composed of a large number of elementary images corresponding either with the various concentric zones of the lens or with the different coloured radiations. The sharpness of the image can also be reduced by fitting the lens with a supplementary uncorrected convergent or divergent lens (§§ 117 and 118) or with a non-achromatic afocal lens (§ 126) or with a very weak convergent or divergent lens, of which the centre is cut out (the sides of the aperture must be blackened).

There are on the market many types of lenses which are incompletely corrected for spherical aberration. They exhibit no peculiarity in use other than the fact that any alteration in the size of the aperture or in the duration of exposure

has an appreciable effect on the result, the image being much sharper when a small aperture, or, within normal practical limits, a short exposure, is used. It is possible to limit the influence of the outer zones of a lens without eliminating them altogether by using a star-shaped aperture, and conversely, to increase their influence by a star-shaped opaque stop. The number of the branches of the star should be odd, in order to minimize the effect on any lines that happen to run parallel to the direction of one of the arms of the star. Certain lenses, more particularly those employed for portraiture, will, if desired, give a perfectly sharp image, or a soft image due to spherical aberration on altering the distances between the various components (obtained by rotation of a ring in a spiral groove). Finally, the spherical aberrations of a Petzval lens can be increased by increasing the distance between the back components, and those of the old type achromatic meniscus ("landscape") lens, by opening up its diaphragm.

Simple or symmetrical non-achromatic lenses (§§ 96, 100, 110), which can be prepared easily from very cheap components (spectacle lenses), have given some very remarkable results in the hands of artistic workers. Their use is often criticized because an adjustment of the extension is necessary after the focusing has been done, and also because widely different results are obtained when light-sources of different compositions are used successively (mercury arc, daylight, incandescent lamps).

332. When using chromatically uncorrected lenses, whether single or symmetrical, in conjunction with an ordinary non-colour-sensitized emulsion or an orthochromatic emulsion without a yellow filter, one has to make certain that the image which is focused by means of yellow-green light, to which the eye is most sensitive, becomes sharp for the blue and violet, to which the emulsion is sensitive. This result is obtained by increasing the camera extension by some 2 per cent.

There is no need for any correction when working with orthochromatic or panchromatic emulsions with a yellow filter. Illumination by incandescent lamps, which are very poor in violet and especially in ultra-violet, or the use of an aesculin filter to absorb the ultra-violet, allows the correction given above to be reduced considerably. One or two trials will show the most suitable amount of correction in given circumstances.

333. Choice of View-point. Although we do not propose, in this book, to discuss the aesthetic

questions which arise in the practice of photography, yet we think it necessary to put the reader on his guard against one or two frequent mistakes.

The most favourable view-point for a subject or a group should be chosen without regard to the scale of the final print, but with sole consideration for the usual rules of composition.

Every photograph should express an *idea*, conveying to those who contemplate the print the same impression experienced at the time the subject was chosen. The picture should contain a *principal subject* (idea of *unity*), and should not combine several subjects, each of which presents a special point of interest, with nothing to unite them. The attention should be drawn immediately to the central theme, the eye being led there, not merely by sentimental interest, but by the convergence of the principal lines and by the contrasts of light and shade, which should be more striking than elsewhere.

No part should be identical with another, and nothing should be symmetrical (idea of *variety*), but there should be a certain balance of lines and tones, conveying an impression of *stability*. The principal lines of the composition, with the exception of the verticals, should not be parallel to one another nor to the frame, but should oppose one another (*opposition*). Balance is obtained, as a rule, by means of an element of secondary interest in the picture (which may be no more than a patch of tone), this secondary feature being placed, for example, at a point diagonally opposed to the principal subject.

By dividing the sides of the picture into an odd number of equal parts, e.g. three, and joining these points by lines parallel to the frame, the *principal lines* are obtained, the intersections of which coincide with the chief points of the composition. The composition may be sometimes facilitated by drawing the principal lines of the picture within the space of the focusing screen of the camera.

It should be noted that a subject which is attractive solely because of its colouring will give very disappointing results in monochrome photography. Some idea of the appearance which a photograph of a subject will present on

an ordinary emulsion and on an orthochromatic emulsion can be obtained by examining it through a blue or a green glass respectively (§§ 226, 236).

The most frequent mistake in composition arises as follows. It is relatively easy for the practised eye to select an attractive subject and to set up the camera in the place considered most favourable. Then, however, it is not at all uncommon for a move to be made to a different view-point, generally much nearer the subject, under the idea that the picture is too small and would not fill the area of the plate to be used. A subject is attractive from a certain view-point because, relative to that point, the lines of the scene are grouped harmoniously, but the attractiveness is generally lost if the view-point is moved either nearer or farther away. Having once selected the view-point, it is better to choose from among the lenses at hand one which will allow the plate to be most nearly filled by the picture, bearing in mind the fact that any unwanted parts may be excluded later. For this purpose a focimeter or an iconometer may be used similar to the frame view-finder described in § 172, the frame being movable along a groove graduated in focal lengths. If, for example, the sides of the frame are equal to a quarter of the corresponding dimensions of the plate, the lengths of the scale graduations attached to the frame will also be equal to a quarter of the various focal lengths to be used. If the picture is considered too small, it can always be enlarged afterwards. (See Chapter V for the rudiments of photographic perspective and the effect of the distance between view-point and subject.)

Having chosen the subject and the view-point, which necessarily fix the angle of the picture and the position of the camera, the limits of the subject are best adjusted by decentring the lens in the direction and to the extent considered necessary (§ 155). Decentring of the lens is practically equivalent to cutting off, from the circular image which would be formed by the lens if a much larger camera were used, that part (equal in size to the plate actually employed), in which the selected subject is best arranged.

CHAPTER XXVI

EXPOSURE

334. Exposure Time. For most subjects there is no single correct time of exposure, but a range of permissible exposures. The minimum exposure corresponds to the condition where in the negative the deepest shadow which is to be recorded is registered as a density only just distinguishable from the chemical fog. The maximum exposure is that in which the lightest half-tones are just distinguishable from the complete block. Of the various exposures possible the shortest one is always the best, having advantages such as greatest speed in printing and enlarging, and least grain.

If the brightness of the subject exceeds that which the photographic material can deal with then it becomes impossible to satisfy both of the conditions mentioned above. This case only occurs rarely, however, and the choice of exposure time then depends on the desired interpretation of the subject.

In every other case the range of permissible exposures measured by the ratio of the maximum and minimum exposures, is given by the exposure latitude, which is obtained by dividing the exposure range of the emulsion by the brightness range of the subject.

Success in photography would be unusual if there were no appreciable exposure latitude. Exposures outside the optimum range, giving pictures in which the shadow or highlight details are lost, are not strictly correct but are often quite satisfactory. If this were not the case the photography of very contrasty subjects would hardly be possible.

335. Results of Errors in Exposure. Negatives which have been given varying times of exposure within the limits defined in the previous paragraph and then developed for the same time in the same bath will only differ from one another in their mean density, and not in contrast. They will give, therefore, identical prints on the same paper, but the printing will take longer in the case of the denser negatives. If, for example, one of them was exposed for five times as long as another and both were developed to a gamma of about 1, then, at a rough approximation, the first will take five times as long as the second one to print, or if equal times of exposure are given in the printing, the first negative will

require five times the intensity of light. These two negatives, while very different in appearance when compared in the same illumination, would appear identical if they were illuminated respectively by a 60- and a 10-watt lamp. They would appear identical under the same illumination if the lesser exposed negative were combined with a neutral density filter or a uniformly fogged and developed plate, transmitting about one-fifth of the incident light. It is essential to note, though, that the over-exposed negative will generally be slightly less sharp, owing to the increased effects of halation, image movement, and graininess.

Of these two negatives, yielding identical results, the professional photographer will always consider the thinner one to be correctly exposed and the denser one over-exposed. Retouching, generally considered a necessary operation in professional photography, is in fact much more easily done on a thin than on a dense negative. He would probably have stopped the development of the more-exposed negative some time before the less-exposed one, in order to obtain greater transparency. The negative developed for the shorter time would then be much less contrasty and would no longer, therefore, yield on the same paper a print identical with that from the other negative, but each could probably be made to give good prints by the choice of suitable papers with characteristics appropriate to the separate requirements of the two negatives.

336. Insufficient exposure always results in a thinner negative than would have been obtained with correct exposure, with lack of detail in those parts corresponding to the darker parts of the subject, and with increased contrast between the images of the shadows and highlights.

It is only in a few special cases that it is possible, by prolonging development, to compensate for insufficient exposure. It would be necessary that all the subject actually covered the lower curved part of the emulsion characteristic and that prolonged development should not give a general fog which would mark the shadow details. Prolonged development of a negative in which the shadows are under-exposed while the highlights are normal only

exaggerates the already excessive contrast between the shadows and the highlights.

It is essential to note that a negative cannot be judged in itself, but only from prints obtainable from it. It has already been stated (§ 258) that the detail on the negative which cannot be seen by the eye often appears in a print made on a contrasty paper.

Over-exposure yields a much denser negative than one which has been correctly exposed and developed under identical conditions, and the contrasts, especially in the half-tones, is reduced. To obtain the same degree of contrast it would be necessary to prolong development, which would result in a further increase in density of the negative. Their liking for a "nice" negative, even though it yields poor prints, causes a large number of photographers to cut short the development, in order to obtain an image in which the mean density approaches that of a correctly-exposed plate developed to the required degree of contrast.

Different considerations apply to reversal materials and thus to all colour materials giving directly a positive transparency. With these the exposure latitude is much less than with the negative-positive process, and secondly, since they are as a rule projected, the aim of "correct exposure" is different. It is simply that the high-lights, such as the sky, or perhaps the tones of a human face, should produce a constant brightness on the projection screen. It would be most disturbing to find, on projecting a ciné film, for example, the face tones varying all the time.

337. Factors Affecting Time of Exposure.

The limits of normal exposure time depend on the illumination of the subject and its tone range, becoming smaller as the tone range increases. The exposure time also depends on the distance of the subject from the camera, the relative aperture of the lens, and the sensitivity of the emulsion, allowing for any colour filter in use.

It is often pointed out that the time of exposure depends on the amount of light falling from the scene on to the lens, or (combining the first three factors mentioned above) on

the intensity of the image on the ground-glass screen of the camera. Many instruments for the measurement of the time of exposure have been based on this method of evaluation. While, in many cases, both these plans lead to practically identical results, it is not difficult to show the inexactitude of the principle and the considerable extent of the errors which are caused when it is applied too strictly. It is, in fact, quite obvious that the same exposure would be necessary for photographing a person behind whom is placed first a white and then a black background, or for a charcoal drawing on paper and a chalk drawing on a blackboard. Yet, in both these examples, the light reaching the lens from the *whole scene* is much greater in the first case, for the mean luminosity of the image is much greater when photographing black lines on a white background than white lines on a black background.

The illumination of the subject depends, as we have already seen (§§ 308 and 309), on the height of the sun and the atmospheric conditions. It is necessary to add to the factors affecting the illumination the altitude of the subject and of the operator. The exposure necessary is considerably smaller in mountains than below, owing to the decreased absorption of the sun's rays by the atmosphere. As a rough approximation, the following relative values of the time of exposure may be accepted for plates and films exposed without interposition of a coloured filter—

Altitude	0 ft	3,000 ft	6,000 ft	9,000 ft	12,000 ft
Relative time of exposure	1	0.75	0.66	0.50	0.3

When, however, the subject is not situated in open country, the extent of sky which can be seen from the position occupied by the subject, and the diffusion of the light by neighbouring objects, both modify the illumination to an appreciable extent. In an interior, for example, the illumination is much greater if the walls and hangings are bright and of light colours.

The brightness of the image varies only slightly with the distance of the object from the lens when this distance is very large, but it

Scale of reproduction	Very small	0.054	0.11	0.20	0.25	0.33	0.50	0.66	1.0
Distance from the camera measured in focal lengths	Very large	20	10	6	5	4	3	2.5	2
Relative times of exposure	1	1.10	1.23	1.44	1.56	1.78	2.25	2.76	4

rapidly becomes less as the object distance and the lens extension become more nearly equal. To compensate for this reduction of brightness, it is necessary to increase the exposure (§ 90). The table given opposite shows, in the case of a flat subject at right angles to the lens axis, the relative exposures for different values of the scale of the image (§ 64) and for the corresponding distances between the subject and camera, the distances being expressed in focal lengths of the lens which is taken as the unit of length.

In the case of solid objects or portraits, these factors should be considerably increased. Small areas of shadow, which need not be reproduced in detail when photographing a distant object, become much more important in a photograph taken at a short distance. For example, when working at 10 focal lengths as compared with a great distance, the most satisfactory picture may be obtained by multiplying the exposure not by 1.2 but by about 30, the exposure being given for the shadows and not the high-lights.

Finally, as already stated (§ 89), the intensity of the image is proportional to the square of the relative aperture. The times of exposure should therefore be proportional to the square of the denominator n in the fraction $1/n$ expressing the relative aperture; in other words, to the square of the F number (§ 71). The lens stops are usually so graded that the exposure must be doubled as the next smaller stop in the series is used. In all this we assume that the reciprocity law holds good. That is not, of course, strictly correct, and difficulties may arise, in particular, with very dimly illuminated subjects, when, for instance, it is necessary to stop down to a large extent in order to increase the depth of field in an interior photograph. The minimum correct exposure with very small apertures can be, at least with certain emulsions, considerably greater than that based on a calculation from the exposure necessary for the same subject using a much larger aperture (see § 205). Failure to take into account the deviations from the reciprocity law often leads to the conclusion that the use of very small stops tends to increase the contrasts, since the calculation of the time of exposure on the basis of its inverse proportionality to the intensity leads to under-exposure, and as we have already seen under-exposure exaggerates the contrasts (§ 336):

It is necessary to point out that in a camera possessing a variable-speed shutter it is preferable to use the diaphragm merely to regulate

the depth of field. Amateur ciné cameras in which there is no adjustment of the shutter aperture are sometimes fitted with neutral grey filters that reduce the light to a known degree so as to reserve the diaphragm for its normal rôle.

Different exposures may sometimes suit one and the same subject better according to the interpretation desired by the photographer. The optimum exposure will not be the same, for instance, for a landscape with figures, according, as it is regarded as open air portraiture or as a landscape with living figures.

338. Influence of Type of Subject on Time of Exposure. Different exposures may be given to the same scene, varying according to the point it is desired to bring out in the photograph. Thus, for example, with a landscape containing a group of people, exposure would have to be greater if the photograph is to be regarded as a portrait than as an animated landscape. We have stated (§ 334) that, in principle, the minimum time of exposure is that which produces a useful image of the deepest shadow and in consequence assures a satisfactory rendering of the details in the darkest tones.¹

This rule is nothing but a re-statement of the old adage, "Expose for the shadows and let the high-lights take care of themselves." There are, however, many instances where the exposure may be considerably less than this minimum, as for example in all open landscapes without any detail in the foreground. The shadows in this type of subject only appear on the image as small patches, and it would therefore be absurd to attempt to bring out their detail. If the photograph is taken with a high-magnification telephoto lens, all objects which stand out in front of the others, even though they are far away from the camera, should be regarded as in the foreground, and here it is necessary to show the detail in the shadows.

Also when a bright subject is being photographed against a dark background it is often advisable to under-expose the latter for the sake of subduing uninteresting details.

The presence of certain details could spoil the effect intended by the artist. This would certainly be the case in a photograph taken purposely against the light, in which it would

¹ We do not deal here with the case of direct positives obtained by reversal or those methods in which the exposure should be adjusted according to the high-lights, such as colour photography and sub-standard cinematography.

be unnatural to record shadow details which could not be detected by the eye under such conditions of glare. A similar case is that of snow scenes, in which it is often much more important to exaggerate a little the play of the light on the surface of the snow than to bring out the details in the shadows, which are usually of interest only for their mass effect. In the same way, when making cloud photographs for the purpose of meteorological studies, any landscape foreground may quite well be ignored; it will be sufficiently represented as a bare expanse without detail.

339. Influence of Movement of the Subject and of the Camera. If, during the exposure, a movement of the subject, of the camera, or of both at the same time takes place, the image will no longer be rigorously sharp. The unsharpness produced will be greater, the greater the velocity of the image in the plane of the sensitive surface, and the longer the exposure. In order to obtain an image which appears sharp no point in it should move more than a certain distance. It is logical to allow the same amount of movement as has already been utilized in considering the depth of field. This, according to circumstances, is about $1/250$ in. in a print giving exact perspective when viewed from a distance of 10 in., or about $1/2,000$ of the focal length in the negative. In pictorial photography a slight unsharpness in the case of a moving object tends to help the suggestion of movement. Here, however, it is a question of personal taste, which cannot be expressed numerically.

On a negative taken with a very prolonged exposure (using a slow emulsion, or a very deep colour filter, or a very small stop) there is no trace of the image of subjects that have rapidly crossed the field. This peculiarity has sometimes been utilized to "eliminate" persons walking in front of a monument or of a landscape.

If the velocity of the image in the plane of the sensitive plate is v in. per second, then the time of exposure t should be such that the product vt is at the most equal to $1/250$ in. or to $F/2,000$ in.

It is easily seen that the velocity of the image on the ground-glass screen or the photographic material becomes smaller, firstly as the scale on which the subject is represented is reduced, and secondly, as the angle between the direction of its movement and the optic axis of the lens becomes smaller. If we call V the actual velocity of subject relative to the camera, θ the angle made between its direction of motion

and the optic axis of the lens, then v , the velocity of the image on a scale of magnification m , is given approximately by $v = Vm \sin \theta$. The velocity of the image, therefore, varies between Vm (when the motion is perpendicular to the optical axis) and 0 (when the motion is parallel to the axis). In this latter case it is not a question of *displacement* of the image but of a progressive change in the scale of magnification.

Based on these facts, it is easy to construct a table showing, for the most usual cases, the maximum time of exposure which may be given. It is necessary to point out that, when photographing a person or an animal running, the speed of the feet is much greater (generally double) than the speed of the body, except for the instant at which they come in contact with the ground. Similarly, when taking photographs with a camera in motion (photographs taken from a moving vehicle or aeroplane) the vibration and swaying transferred to the camera, will, at certain instants, considerably increase the velocity of the image.

Unless absolutely necessary, there is no sense in taking a photograph if the maximum exposure indicated by this method falls considerably below the minimum time of exposure worked out on the basis of the sensitivity of a plate or film, or is less than the shortest exposure which the shutter in use is able to give.

A successful photograph can often be obtained, however, by the method of "swinging" the camera. For this the camera is kept pointing at the moving object, preferably by watching it in the view-finder and moving the camera so as to maintain the object at a fixed position with respect to the camera. Under these conditions, with an exposure appreciably longer than the calculated value, it is possible to obtain a sharp image of a moving object, while the image of all stationary objects will be indistinct, each point in them being displaced in a direction parallel to the line of movement.

In the nomogram shown in Fig. 26.1, the maximum exposure times can be worked out, the limit of sharpness being $1/2,000$ of the focal length, and the object moving at right angles to the camera axis.

The speed of the object (or of the camera, if a photograph is taken from an aircraft or other vehicle) is shown on the scale on the left, and the distance between the camera and the object (the foreground, if the camera is moving) on the right. A line connecting the corresponding points on these two scales cuts the third scale

at the maximum admissible exposure time. Thus, for example, the line drawn shows that for an object moving at 6.2 miles per hr, 60 ft away from the camera, the exposure time should be $1/1,000$ sec or less.

This maximum time of exposure may be doubled, if the path of the moving object lies at 45° to the lens axis, and trebled, if it runs parallel to it.

340. Instantaneous and Time Exposures. From the point of view of carrying out the operations, there is no real distinction between instantaneous and time exposures; it is probably more correct to say that there is no such thing as an instantaneous exposure. Every negative is more or less exposed; a negative which has been exposed for a long time may still have had insufficient exposure, while a negative exposed only for a few thousandths of a second may be over-exposed.

A misunderstanding, probably due to the wonderful promises made by certain dealers, has led many novices to believe that, once possessed of an instantaneous (snapshot) camera they have only to press a button to obtain excellent photographs with certainty in about $1/25$ second, whatever the time or place, even though it be in the depths of a tunnel, or on a moonless night!

In fine weather in the open, nearly all the objects within the field of view may be readily seen if the eyes are open and shut as rapidly as possible. In bad light the same instantaneous blinking of the eyes will reveal only those objects which are more strongly illuminated than the rest; the whole view will be seen only after a long and close inspection. The photographic plate behaves very similarly. This obvious fact should lead beginners to a proper understanding of the possibilities of their cameras.

341. Practical Determination of the Time of Exposure. The professional, who is always working in the same studio on subjects which differ photometrically very little one from another very soon acquires the practical experience which enables him to estimate the time of exposure with an accuracy which nearly always brings it within the limits of normal exposure. This applies especially to portraiture, where the restricted range of contrasts increases the latitude of exposure.

The amateur, whose photography is done only during the best months of the year and who confines himself almost entirely to subjects of the same character, frequently attains, but

not without spoiling an appreciable number of plates or films at the beginning of each season, a certain skill in judging the exposure, roughly, it may be, but closely enough to enable him to obtain satisfactory negatives. The success of the box camera, with fixed aperture and a single instantaneous and time shutter, bears this out.

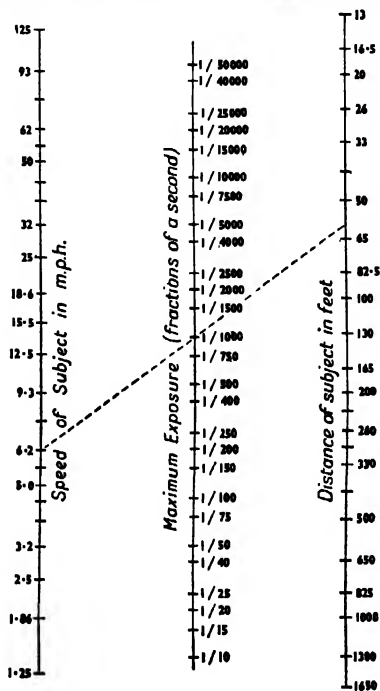


FIG. 26.1. GRAPH FOR THE ESTIMATION OF MAXIMUM SHUTTER SPEED FOR A MOVING SUBJECT

It is more difficult to be sure of the correct exposure in the case of the photographer, who, from necessity or choice, attempts successively a very wide range of subjects, sometimes exterior, sometimes interior, or for the worker who through force of circumstances has to operate in a climate to which he is unaccustomed. Under these conditions, through errors of judgment, the exposures very frequently fall outside the limits of normal exposure, causing a high proportion of useless negatives. Hence many workers will make at least two negatives of a difficult subject, in the hope that at least one of them will prove acceptable.

Numerous instruments, known as exposure meters, have been on the market for a long time, but have not, in general, established themselves. The use of exposure meters has been encouraged, however, both by the very small exposure latitude of modern colour and reversal materials, and by the general increase in price of photographic materials in general.

In order to obtain the maximum benefit it is necessary to choose an exposure meter based on a logical principle. Unfortunately, this does not apply to all meters available, including some of the most popular.

Where no meter is available, quite good results will be obtained from the use of an Exposure Table or Calculator.

342. Exposure Meters. Certain exposure meters allow the brightness of any one convenient small area in the field to be determined. Many other meters measure the equivalent of the luminous flux passing through the camera lens, or more exactly, the average brightness of the scene. The measured value is often influenced to an undesirable degree by the amount of sky included in the field of view of the meter. Not all the meters on the market are designed upon sound principles, but are still capable of giving useful indications, both because they are calibrated empirically and because of the wide exposure latitude of modern photographic materials.

We have already considered how the nature of the subject, and the kind of photograph one wants to obtain, influence the optimum exposure time. It is clearly too much to expect that even the soundest and most accurate exposure meter is capable of taking account of these factors. Thus, it is necessary to interpret intelligently the indications of the meter. Several meters provide correction factors which depend upon the nature of the subjects.

Exposure meters may be classified into those which depend upon the chemical action of light, upon visual effects, and upon electric effects. Meters of the last two kinds may be coupled to the lens diaphragm or the shutter of the camera; with photo-electric meters, the lens diaphragm or shutter speed may be set automatically.

Exposure meters also require a table of relative speeds of the various photographic materials and a calculator, which allows the various combinations of diaphragm and shutter setting, which will give adequate exposure, to be determined rapidly from the meter reading and the speed of the material.

The calibration of exposure meters is very often such as to give the minimum exposure that can be used. It is thus a wise precaution to double the exposure indicated. Over-exposure is never as fatal as under-exposure. This increase in exposure should clearly not be applied if the subject covers a wide tone range, or if a colour material is used, or with reversal materials in general.

Under all circumstances, the filter factor must be taken into account.

An interesting comparison of the usefulness of different types of exposure aids has been published by J. Milbauer (1937). He used a panchromatic roll-film of considerable exposure latitude, wide enough to allow exposure differences as much as 250 : 1 on the same scene, the resulting negatives still giving satisfactory prints on the same grade of paper. For each instrument the average rate of success was determined, all those negatives being considered as satisfactory which could still be printed on medium contrast paper. The table below summarizes his results.

Type of instrument	No of instruments tested	Percentage of successes		
		Minimum	Maximum	Average
Tables	15	27	94.5	45
Calculators	11	27	67	47.2
Actinometers	6	63	94.5	84.5
Visual (extinction meters)	21	76.5	100	87.8
Photo-electric meters	10	85.5	100	97.1

343. Actinometers. An actinometer has been described as early as 1840 by J. B. F. Soleil for use by workers making Daguerrotypes. This instrument utilized a moist silver chloride paper fixed to the bottom of a long tube which was pointed at the subject. The exposure was stopped when the paper had reached a pre-determined tint.

For many years the actinometer held the field as the only instrument capable of determining times of exposure with reasonable accuracy. The instruments constructed by A. Watkins (1890) and G. F. Wynne (1893) combined an actinometer proper with a circular calculator on which the exposure time was worked out from the time necessary for the actinometer paper to reach a certain colour. These instruments enjoyed a well-merited reputation.

344. Visual Photometers for the Measurement of the Brightness of a Small Area in the Scene. Taylor has described (1866) the use of a visual

photometer as an exposure meter. He suggested that a field illuminated by the subject should be compared with another field illuminated by an auxiliary source of light. Instruments of this type have been used for cinematography by D. F. Comstock (1916). Illumination meters have also been utilized in film studios to ensure that the illumination is sufficient all over a set.

The most convenient layout for a visual photometer comprises a small telescope through which the scene is viewed, and a transparent reflector through which the filament of a small electric bulb is seen at the same time in the centre of the field. The lamp is supplied from a torch battery. The brightness of the filament can be controlled continuously either by means of a variable resistance in the lamp circuit (F. N. Norton, 1927), or by a neutral density wedge which must be calibrated in position in the instrument (W. Gunther, 1927; L. Lobel, 1929). The lamp brightness is varied until the filament disappears, when the field brightness is equal to that of the filament. The brightness of the subject can then be read off a scale which is attached to the control which varies the lamp brightness. By means of a calculator, the exposure time can then be worked out.

An exposure meter based upon this principle will give exact exposure readings even under the most difficult conditions. The part of the subject to be measured is, as a rule, the deepest shadow in which one wishes to record detail in the print. For reversal work, a reading would be taken on a high-light. The main criticism levelled against these instruments is that they are clumsy, largely because of the size and weight of the dry battery they contain.

An interesting new version of a visual photometer has been described by J. F. Dunn and G. S. Plant (1945). In this instrument a photoelectric cell is used to bring the comparison lamp to a standard brightness so that the instrument is self-calibrating. The comparison field measures but $\frac{1}{3}^\circ$; unfortunately, the instrument is rather expensive.

345. Other Visual Exposure Meters. With a very old type of exposure meter (C. F. Albinus, 1844) the subject is viewed through a pair of blue or grey wedges so arranged as to form a plane-parallel layer of varying thickness and density. Each prism carries an index along a scale. One of these scales is set according to the lens aperture and the sensitivity of the material, the other scale is calibrated in exposure times. One of the wedges is set according to the known

operating conditions. The other wedge is moved until the details in the scene begin to disappear and the exposure time to be used can then be read on the second index. Innumerable variations of this device have been constructed in all countries and are described as extinction meters.

With these instruments, precautions must be taken to avoid the effect of adaptation of the eye, i.e. the inevitable increase in sensitivity of the eye when looking into a dark aperture. Thus some instruments have fixed into the eyepiece a diaphragm with an aperture smaller than the minimum pupil diameter of the eye, to avoid the errors due to the dilation of the pupil under weak illuminations (G. Heyde, 1905); another method is to surround the field of view by an annular field of higher brightness (W. Schlichter, 1926). The result of the adaptation of the eye is to over-estimate the brightness of dimly illuminated scenes and to under-estimate that of scenes in bright weather. Thus users are often advised to double the exposure time indicated for a bright scene and to halve it for dark scenes.

Certain instruments are designed to be attached to the ground-glass screen or to be combined with the viewfinder of the camera and comprise a wedge or a series of stepped densities, which are carried by a film stretched between two spools, and which weaken the image until the details disappear.

Similar results are obtained if the image of the scene is observed on the ground-glass screen while the iris diaphragm of the camera is being gradually closed. The point of disappearance of the shadow detail can be used to determine the exposure time. To calibrate, a photograph of the scene should be taken with the aperture found and a series of exposure times increasing in geometrical progression. One of the negatives thus obtained will be found satisfactory, and the relation between the aperture for which image detail disappears, and the exposure time, can be established.

Whenever extinction meters are used, it is useful to standardize on the time taken over a measurement. The effect of adaptation of the eye is that more and more detail becomes visible the longer the time taken over the measurement. If the time of measurement is standardized to, say, three seconds, the effects of adaptation will be minimized.

Various instruments have been designed which allow the exposure time to be determined from a

measurement of the diameter of the pupil of an observer viewing a scene (A. Lipowitz, 1844); it has even been suggested that the pupil of a cat might be a suitable measuring instrument (Cussen, 1844). There is no sense in dealing with these fantastic ideas in detail, although they have been the objects of some recent patents.

346. Photo-electric Exposure Meters. W. E. Story (1921) used a photo-electric (emission) cell for cinematography in the studio. The cell was housed at the bottom of a long tube and was aimed at the subject by means of a view-finder. An exposure meter of this type was suitable for industrial use only, since the cell requires an external source of high voltage, an amplifier and a galvanometer. The discovery of the photo-voltaic cell dispensed with the need for an external supply of energy and allowed the development of handy exposure meters small enough to be carried in the pocket (H. F. Tonnies, 1930).

The most sensitive *photo-voltaic cells* (E. Falkenthal, 1930) consist of a thin layer of grey selenium deposited upon a disc of iron which forms the positive electrode (anode) of the cell. The selenium layer is covered by a very thin transparent layer of a metal, such as lead, gold, or platinum, which forms the negative electrode (cathode) and which is covered by a layer of protective varnish. On exposure to light, the cell generates a small voltage.

This discovery was originally made (L. O. Grondahl, 1926) on the superficially oxidized copper plates used as electric rectifiers. All photo-voltaic cells have rectifying properties and are therefore often called barrier-layer cells. These cells should not be confused with the original photo-electric cells, which more accurately might be described as *photo-emission cells*. Photo-voltaic cells display large local variations in sensitivity which may vary as much as 60 per cent over the surface of a single cell. The sensitivities of cells from different sources may differ by as much as 5 to 1; their spectral sensitivities also vary considerably, and local differences in sensitivity for coloured light may be greater or smaller than those for white light (J. Mrozowska, 1938). All these differences can be kept within reasonable bounds, however, with the cells produced in any one factory.

During exposure to light, the photo-voltaic cell may be regarded as a source of electromotive force, shunted by the resistance of the selenium layer, and feeding into an external resistance, which comprises the windings of the micro-ammeter and often also an additional separate

resistance. For weak illuminations, the shunting resistance is large, becoming smaller as the illumination increases. For weak illuminations, the current output from the cell is almost exactly proportional to the illumination of the cell, but for higher illuminations, an increasing fraction is by-passed within the cell. This effect is more pronounced the greater the external resistance and causes a compression of the scale at the high-illumination end. This compression is very desirable, since for an exposure meter the ideal scale is logarithmic, thus covering a wide range of illuminations which can be measured combined with high sensitivity for small values of the illumination. By special design of the micro-ammeter (§ 347), a nearly accurate logarithmic scale can be obtained.

The sensitivity of a photo-voltaic cell is of the order of 120 micro-ampere (μA) per lumen. The micro-ammeter generally has a resistance from between 750 to 2,000 ohms. If this resistance is 1,000 ohms a cell of dimension 17 by 35 mm ($\frac{2}{3}$ by $1\frac{1}{2}$ in.) has an output of 65 μA for 300 metre-candles, 100 μA for 600 metre-candles and 250 μA for 6,000 metre-candles.

The spectral sensitivity covers the range from 300 to 800 $m\mu$, with a strongly pronounced maximum at around 600 $m\mu$. In the blue, the sensitivity is considerably less than that of a photographic material used without filters, but higher than that of the eye. These differences are much smaller in the red, and for a panchromatic material used with a yellow filter the spectral sensitivities agree quite satisfactorily. In order to achieve really accurate agreement of the spectral sensitivities, it would be necessary to use a correction filter over the cell which would reduce its sensitivity to uselessly low values. It is therefore not practicable to determine the exposure to be used with a filter over the camera by using this filter over the cell of the exposure meter. For colour photography, it is recommended to apply an ultra-violet absorbing haze filter over the cell, made from a certain special glass used for spectacles, which is practically colourless, in thicknesses from 2 to 3 mm (P. C. Smethurst, 1939).

The usual photo-electric exposure meters cannot be used to determine the exposure for infra-red photography out of doors, since the sensitivity of the cells towards infra-red is very small compared with that to visible light, and since no relationship exists between the amount of visible and infra-red in daylight. Cuprous oxide cells would be more suitable

for the purpose, but would have to be used in conjunction with an infra-red transmitting filter and be specially calibrated.

347. The most common method of use of photo-electric meters is to point them at the subject from the camera position, thus measuring the luminous flux coming from the scene. When used in this way, it is preferable for the acceptance angle (defined as the total solid angle from which light can reach the cell of the meter) to be no larger than the field of view of the camera. It is inevitable that the acceptance angle includes some of the sky of an outdoor scene, and because of the high brightness of the sky, the amount of sky included has a large influence upon the meter reading obtained. Although the acceptance angle of many meters is sufficiently nearly equal to the field of view of the camera, the uncertain amount of sky included makes the exposure indications obtained somewhat uncertain.

The acceptance angle of a meter is often limited by a hood, the depth of which can be made to control the angle within certain limits. Another method is to arrange a cellular grid in front of the cell; with yet another the angle is limited by a cellular array of optical lenticular elements, making up a multiple camera rather like an insect's eye. The acceptance angle is sometimes limited to a cone in the shape of a pyramid, and sometimes to a circular cone. Since the various cameras cover fields of various shapes and sizes, according to the focal length of the lens, the angle of the cell will only roughly coincide with that of the camera. Thus there is always the risk that an object of high brightness, included into the angle of the cell but not the camera, introduces an appreciable error. There are wide variations between the acceptance angles of the different meters. Thus the horizontal acceptance angle is often greater than the vertical, but the converse also occurs. The use of a large acceptance angle allows the designer to use a cheap galvanometer movement, since the amount of light reaching the cell and therefore the current, is large.

One make of exposure meter succeeds in decreasing the amount of sky light relative to that coming from the ground by arranging a converging lens in front of the cell and a shield somewhere between the cell and the lens. This construction removes one of the worst causes of error in landscape photography, but it introduces a new one for those subjects which do not contain any sky.

The micro-ammeter consists of a permanent magnet made of cobalt steel or one of the modern magnetic alloys, in the magnetic field of which swings a coil wound from several hundred turns of fine insulated copper wire. The current from the cell passes through this coil, which is mounted on steel pivots supported by sapphires. Two hair-springs serve both to lead the current into and out of the coil and to limit its movement. In order to increase the range of brightnesses that can be measured, the instrument is designed so that the coil moves gradually out of the magnetic field as the current increases. A further method of compressing the scale is to modify the magnetic field by means of soft iron, and by using an additional resistance in series with the cell and the coil.

The scale of the meter will differ according as the instrument is to be used for still or for ciné work. A meter for still photography thus often indicates the exposure time to be used with an arbitrarily chosen aperture and film speed; a table, a nomogram, or a calculator then allow the exposure time to be worked out for any other conditions. A ciné meter will as a rule indicate the lens aperture for a fixed shutter opening, usually taken as 180°.

With certain meters, the calibration of the scale is distorted so that the exposure is relatively heavy for poorly lit scenes; in this way deviations from the reciprocity law (§ 205) are taken care of. There are, however, meters in which the scale calibration is distorted in the opposite sense. It is therefore recommended to check a meter by taking readings at various distances from a constant small source of light. This is best done in a darkened room, using a lamp enclosed in a housing with but a small aperture opposite to the lamp; in this way no light will reach the walls or other objects in the room and errors due to scattered light will be avoided.

348. **The Method of Use of Photo-electric Exposure Meters.** The sensitivity of a cell is reduced by some 25 per cent as the temperature falls from +35° to -15°C; this variation is unimportant in practice, considering the exposure latitude of photographic materials.

Photo-voltaic cells are liable to lose their sensitivity if exposed continuously and should therefore be protected except for the time necessary to make a measurement.

Serious systematic errors may be caused if the micro-ammeter is disturbed by jerking or dropping the instrument; the meter should then be repaired, or at least, the calibration should

be checked. Mishandling of the instrument is liable to cause sticking of the meter, so making the measurements unreliable and thus worse than useless. To see whether the instrument sticks, it should be tapped lightly; the deflection should not change to an appreciable extent.

Strong electric or magnetic fields, or large masses of iron or steel, are liable to upset the micro-ammeter temporarily, so that wrong readings might be obtained.

The range of illuminations on the cell, which can be measured, varies considerably with the different meters. In order to increase the sensitivity, one type of meter uses supplementary cells, which are plugged into the body of the instrument in parallel to the main cell of the meter, the calibration of which is then suitably altered (A. Bernhard, G. Beyrich, and H. Habermann, 1935).

The most common method of use of exposure meters consists in pointing them at the subject to be photographed, taking in a field of view as nearly as possible equal to that of the camera. It is surprising to note that this relatively crude method, consisting as it does in a measurement of the average brightness of the scene, should be capable of giving a reasonably reliable indication of the exposure required. In fact the method is quite successful, no doubt because the normal scene taken by the amateur contains much the same light and dark areas. One of the meter manufacturers recommends that allowance be made for the average tone of the scene. Thus a scene containing very large sky areas will produce a large deflection of the needle and should be given a heavier exposure than indicated. Where the subject comprises a large area of sky, it is advisable to point the meter slightly downwards, in order to reduce the influence of the sky brightness. On pointing the meter progressively downwards in this way, it will be noticed that the meter needle suddenly drops sharply. In this position the meter has just stopped taking in the sky, and more reliable exposure indications are obtained (G. B. Harrison, 1939). It is necessary, of course, to recalibrate the meter, if it is to be used in this fashion.

An exposure meter used from the camera position indicates an exposure which will produce a constant average density for negatives exposed to the various types of scene. For the large majority of scenes photographed, the ratio of dark to light areas is sufficiently constant to allow this crude method of use to give

a satisfactory indication of the exposure. For subjects of high average brightness, the exposure indicated will tend to be short; for dark scenes, too long. It is often said that the advantage of an exposure meter is to replace judgment by measurement; one must not forget that when used from the camera position, the meter measures a value which is connected with the correct value merely by a chance accident.

A much more reliable method of using the meter consists in pointing the meter at an artificial constant tone temporarily incorporated into the scene, large enough and near enough to fill the acceptance angle of the cell. The meter must of course be calibrated for this method of use, and care must be taken not to throw a shadow on the test surface. The tone of the test surface should be near to that of the shadows of the scene in the case of normal photography or a clear white for reversal methods (G. B. Harrison, 1934).

Another method of use is to determine the brightness range of the scene by measuring both the extreme high-lights and the shadows. Such measurements would be useful in deciding whether it was permissible to increase the exposure or whether it might be necessary to decrease it in order to render correctly the high-lights in a contrasty scene.

For photography in artificial light, a correction factor must be applied, which varies both with the nature of the source of light and the emulsion used. For tungsten light and panchromatic emulsions, the correction factor ranges from 1.25 to 1.6, the lower value applying to lamps of higher colour temperature, such as the photoflood lamps. For orthochromatic emulsions the value is from 2.5 to 4, and for blue-sensitive emulsions, it is of the order of 4 (B. Schönwald, 1934).

For subjects lit from the side or the back, a meter will generally tend to indicate too great an exposure, which is particularly troublesome in colour photography. It has been suggested that this error might be obviated if a smaller cell were mounted so as to receive light from the sky, the small cell being connected in opposition to the principal cell of the meter (O. Riszdorfer, 1939).

349. When working in artificial light, two factors affect the readings of the meter in opposite direction. Out of doors, the acceptance angle of the meter covers as a rule some portion of the sky, and thus the average brightness measured is higher than that of the

subject proper. In artificial light, on the other hand, the edges of the field are often poorly lit, and are thus less bright than the main subject. It is thus necessary to reduce the time of exposure obtained to at least one half and perhaps even one quarter of that indicated by the meter if the ceiling is dark (J. Eggert and A. Küster, 1940).

When the meter is used to determine directly the brightness of the principal object by means of the method outlined in the previous paragraph, the discrepancy between the spectral sensitivities of the cell and the emulsion means that the exposure time indicated is too short. This effect is greater the greater the difference in the spectral sensitivities, i.e. increasing in the order panchromatic, orthochromatic, blue-sensitive emulsions.

350. A photo-electric exposure meter can be used as an illumination meter, determining the exposure time by the illumination incident upon the scene. With this method, the illumination of, say, a shadow region would be measured by placing the meter into the shadow region facing the camera lens. Again, this method requires the meter to be specially calibrated. The illumination value should be multiplied by the reflectivity of the surface under consideration in order to obtain a value for its brightness. The reflectivity can be found easily by comparison with a calibrated grey scale. The brightness value so found can then be used to obtain the exposure value, using a table or nomogram obtained by systematic experiments.

Photo-electric illumination meters, actually calibrated in foot-candles, are used in ciné studios in order to make certain that the illumination in the shadow regions is above the minimum necessary for detail to be shown adequately under the operating conditions chosen.

Again for cinematographic work, a brightness meter has been used which allows the brightness of a very small area anywhere in the scene to be determined with great accuracy. A reflex view-finder equipped with a high-aperture lens throws an image of the scene on to a ground-glass screen, in the centre of which is marked a square of side $1/8$ in. By pressing a button the mirror is thrown out of the way and the image of the small area chosen falls on to a small aperture in front of a photo-emission cell. If a sodium cell is chosen, its spectral sensitivity is nearly equal to that of a panchromatic material. The photo-current is amplified and fed

into an indicating instrument calibrated in brightness units (F. C. Whalen, 1935).

Because of the different requirements of reversal (colour) materials, "high-light" meters have recently become more popular. With these the sensitive surface is covered by a piece of opal material. The cell effectively measures the illumination falling on the opal material; in other words, it measures the brightness of an artificial high-light. The resulting exposure will then ensure that a high-light will have the same constant density in the transparency.

351. **Coupled Exposure Meters and Cameras.** A. Watkins (1904) has suggested for a visual extinction exposure meter to be coupled to the camera adjustments, i.e. either to the shutter or the diaphragm, taking care also of the sensitivity of the emulsion. This scheme has been applied to hand-and-stand cameras since 1926, the meter often being combined with the view-finder in order to save time. Instruments utilizing photo-emission cells inside ciné cameras have been employed by R. E. Naumann (1926) to measure the average brightness of a scene.

As soon as the photo-voltaic meters were developed they were coupled to still and ciné cameras. Various methods of coupling have been suggested. With the mechanical method, the act of setting the camera adjustments operates a pointer which has to be brought into opposition to the needle of the meter; with the electrical method, both camera adjustments are connected to a variable resistance in the cell circuit and are moved until the indicator needle is opposite to a fixed mark. With yet another method, the setting of the camera varies the position of a diaphragm or a set of flaps in front of the cell, thus altering the amount of light reaching the cell. Again, the adjustments are altered until the needle coincides with a fixed mark.

Numerous modifications of these principles have been suggested and made: thus the shutter release may be blocked until the setting is correct: the device may be calibrated so as to show whether there is still a chance of a successful exposure, even when the needle cannot be made to coincide with the fixed mark.

Coupled exposure meters are clearly most efficient only if the needle is visible either in the view- or the range-finder. Ingenious solutions have been found for the problems involved in cameras with interchangeable lenses.

352. **Automatic Camera Control by Photo-electric Cells.** Experimental devices have been

produced (C. O. Raab, 1929) which control automatically the diaphragm of a ciné camera by means of a photo-emission or photo-conduction cell, both of which require an external source of electricity. No practical successes were achieved before the arrival of the photo-voltaic cell (O. Riszdorfer, 1930).

As a rule, it is the diaphragm which is controlled automatically, after the shutter speed and the film sensitivity have been set on a slider. These settings modify either the current by varying resistances in the cell circuit, or the amount of light reaching the cell, or even the sensitivity of the galvanometer by varying a magnetic shunt. The galvanometer coil may itself vary the diaphragm, or more often, the position of a stop which limits the travel of the diaphragm setting so that it cannot be closed below the diameter necessary for correct exposure. The energy necessary to close the diaphragm down to the stop may be derived from the film transport mechanism, the setting, or the release of the shutter. The diaphragm may then be returned automatically to its fully open position after the exposure is completed. (J. Mihalyi, 1936).

When a colour filter is used, the photo-current should be reduced; one of the methods of achieving this is to reduce the cell area by means of a fixed diaphragm which is part of the mounting of the filter.

Some method of uncoupling the automatic feature is usually provided for for exposures under very poor lighting conditions.

353. Light Integrators. Natural light and even artificial light is subject to continuous fluctuations due for example to voltage changes, to insufficient control of arc lamps, or to the variations in time before metal vapour lamps reach equilibrium conditions. For these reasons, readings on an exposure meter may be of little value and an integrator for the light may be required, in particular if exposures are long, such as in photo-mechanical work, or if exposures must be reproduced exactly, such as for tricolour separations.

For this purpose an actinometer may be used (§ 343), held next to the document to be reproduced, the exposure time being either equal to the actinometer time or being a certain multiple of that time; we shall deal below in some detail with these methods of copying (Chapter XLVIII).

The more modern types of integrators utilize a photo-voltaic (H. Geffken & H. Richter, 1930)

or a photo-emission cell. The photo-current produced by a pre-set total amount of light received by the light-sensitive organ actuates a relay, which either closes a shutter, switches off the lamps, or causes a visible or audible signal to be emitted. It is interesting to note that already in 1899 J. Poliakoff had described an instrument working upon similar principles. He arranged a photo-conduction cell behind a photographic plate carrying a print-out emulsion. By means of a relay, the photo-current kept the shutter open until the plate was blackened sufficiently to cut down the illumination on the cell and thus to close the shutter. As a curiosity may be mentioned the suggestion (L. Vidal, 1877) to use a Crooke radiometer as a light integrator by counting the number of revolutions.

In the photo-voltaic integrators, a cell of large dimensions is used, which is so arranged that the current is at any one moment proportional to the illumination. The cell may either be connected to a micro-ammeter, when the instrument becomes an illumination meter, which can be utilized to check the evenness of illumination over the document or the scene. To serve as an integrator, the cell is connected to an electric counter requiring very little energy. The indicator of the counter moves over a scale graduated in metre-candle-seconds. When the indicator has reached a pre-set mark, a relay is operated.

With integrators employing photo-emission cells, which are more complicated and more fragile, the photo-current is amplified and used to charge a condenser. When the condenser charge reaches a certain critical value, it discharges across a gas-discharge tube and electromagnet, which causes a counter to advance by one unit.

354. Calculating the Exposure Time. If B is the brightness of a small shadow area, within which detail should be distinguished, the illumination E falling on to the corresponding portion of the photographic plate can be calculated as follows. The case of an object situated on the lens axis at infinity has been considered earlier (§ 89). If the area considered is situated on a secondary axis making an angle of 15° with the optic axis, its effective brightness is reduced by a factor of 0.87, and the effective aperture of the lens is reduced by a factor of 0.8 of its value on the axis. If now the transmission factor of the lens is 0.7, the illumination on the plate becomes $E = 0.87 \times 0.8 \times 0.7 \times B/4n^2 = 0.38 B/n^2$.

If the subject is situated at a distance m

times the focal length, the illumination should be multiplied by a factor $(m-1)^2 m^3$, which is for example, 0.95 for $m = 40$.

If we call E_0 the illumination which corresponds to the speed criterion adopted, the exposure time giving adequate exposure in the shadows of the scene is $t = E_0/E$. This is the minimum exposure time which, except for subjects of wide tone range, might well be increased by a factor of 2.5, in order to take care of any lack of precision in the measurements of B , n , or t (L. A. Jones and H. R. Condit, 1941).

355. Exposure Tables. Exposure tables and calculators indicate the probable time of exposure under conditions which, in so far as it is possible to define the state of sky and the characteristics of a subject by a few words, are comparable to those under which it is proposed to operate. They are, above all, useful to the beginner, who, in his first attempts, has no idea whether the exposure should be of the order of a second or of a minute. They are also of service to those who take up photography only occasionally, and therefore have no past experience to go by. We have already pointed out (§ 342) that the use of these exposure tables gives a probability of success about equal to that obtained by the use of certain types of visual photometers.

Exposure tables indicate, in separate graphs or tables the values of the light at various periods during the year, and at various hours of the day for different conditions of the sky, the factors corresponding to the different lens apertures, and those applicable to the different classes of subject according to the probable illumination of the shadow (near scenes) or of the high-lights (distant scenes). In some tables the numbers taken from each of the tables are multiplied together, their product representing the probable time of exposure for a certain type of emulsion. In other tables the numbers are added (an operation which is much more easily carried out in the head), a final table then indicating, opposite each of the possible totals, the corresponding times of exposure (Additive Number Tables of E. Huillard and E. Cousin, 1894). Finally, in other methods, the conditions relating to each of the factors are arranged along a scale or around a disc or circular calculator.

An exposure table should only be used in the district for which it has been compiled, or at least for districts of the same latitude if due correction is made for the variation in time. Special attention should be paid to any possible

discrepancies between "legal time" and solar time. Further, the tables are very unreliable in bad light. Usually they give no indication of the time of exposure necessary for interior work, for the variations likely to arise makes any attempt at description impossible.

The exposure tables given here are calculated for the south of England. The values should be increased in the north and decreased in regions farther south.

The curves in Fig. 26.2, which supply the data for use in the table headed *Atmospheric Conditions*, each refer to a definite height of the sun above the horizon. This may readily be determined by measuring the length of the shadow cast on a horizontal plane by a stick one yard in length. Such values corresponding to this series of curves are given in the following table under their respective letters. It should thus be an easy matter to extend the use of these tables to other regions.

Curve Length of the shadow of a stick one yard in length	A	B	C	D	E	F	G	H	I
	0.5	0.6	0.8	1	1.5	2	3	4	6 yd

356. The Exposure. Having determined the time of exposure, set the shutter to the "speed" which approximates most closely to the required value.

As a general rule, times of exposure exceeding 1/10 second cannot be given unless the camera is fixed on a tripod or some equivalent support. The beginner will be wise to refrain from giving any exposures exceeding 1/25 second with the camera held in the hands.

When working with a hand camera, the elbows should be pressed firmly against the body to form a support for the forearms, and the breath should be held at the moment of releasing the shutter. Folding cameras can often be supported with one hand, the camera being supported in the crook of the arm. The other hand is thus left free for any other manipulation as, for example, the release of a flash.

The beginner and those who are using a new camera for the first time, or a type of emulsion to which they are unaccustomed, cannot be too strongly advised to make a note of the exposure conditions (lens aperture, the time of day, exposure-meter reading or description of the atmospheric conditions, colour filter used, time of exposure), in order that any errors which arise may be readily corrected in the future.

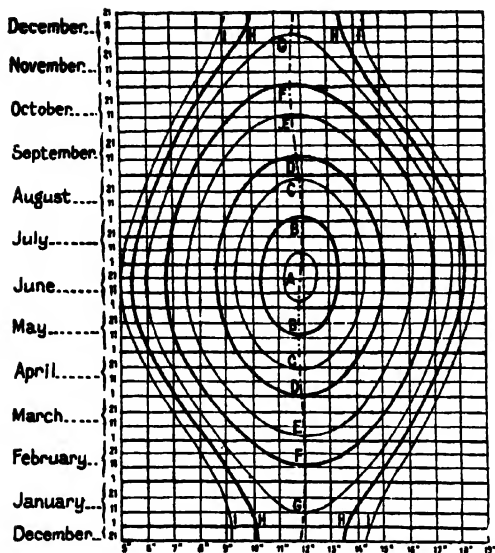


FIG. 26.2 CURVES OF EQUAL LIGHT-VALUES
(Greenwich Mean Time)

TABLE I
ATMOSPHERIC CONDITIONS

Curve (hour and date)	A	B	C	D	E	F	G	H	I
Sunshine, strong shadows	0	0	1	2	3	4	5	7	10
Hazy sun, weak shadows	2	2	3	4	5	6	7	9	12
Cloudy, light	3	4	5	6	7	8	9	11	14
Cloudy, dark	8	9	10	11	12	13	15	17	20

N.B. The first line should only be used for very open subjects (panoramas, marine views, etc.) where the foreground is of no interest; in all other cases, use the second line instead.

TABLE II
SUBJECTS

Marine or snow scenes, no foreground	0
Open landscape, no foreground	3
Ships on the sea, beach scenes, glaciers and rocks	5
Landscapes with foreground	8
Portraits and groups in the open, wide streets and squares	10
Landscape with dark foreground, shady courtyards, narrow streets	13
Portraits and groups in the shade	15
Under trees, light	18
Under trees, dark	24

It is also advisable, when taking consecutive photographs of a series of subjects which cannot be readily identified, to note down any necessary information concerning each subject. This will avoid confusion in identifying the negatives.

EXPOSURE TABLES

In Fig. 26.2 read the letter on the curve which passes nearest to the point corresponding to the date and the time. Then, in Table I under this letter, read the number which corresponds to the atmospheric conditions (thus, 1st May at 4 p.m., curve *F*; sunshine, strong shadows, 4). Now, in Table II take the number referring to the particular type of subject (for example, group in the open: 10). In Table III find the number corresponding to the size of aperture (lens at $f/6.3$: 13). Finally, add these three numbers together, $4 + 10 + 13 = 27$, and, in Table IV, read the time of exposure opposite this total (1/100 of a second).

TABLE III
DIAPHRAGM

$F/1.5$. 0	$F/4$. 9	$F/8$. 15	$F/22$. 24
$F/2$. 3	$F/4.5$. 10	$F/9$. 16	$F/32$. 27
$F/3$. 6	$F/5.6$. 12	$F/11$. 18	$F/45$. 30
$F/3.5$. 7	$F/6.3$. 13	$F/16$. 21	$F/64$. 33

N.B. For very near subjects, increase the total obtained by 1 to 6 units (the latter increase applies to the case of a small object reproduced in natural size).

TABLE IV

These exposure times apply to fast orthochromatic and medium speed panchromatic film.

Total	Time of Exposure	Total	Time of Exposure
13	1/2500 of a sec.	47	1 sec.
14	1/2000 " "	50	2 " "
15	1/1500 " "	53	4 " "
17	1/1000 " "	56	8 " "
20	1/500 " "	59	16 " "
24	1/200 " "	62	32 " "
27	1/100 " "	65	1 min.
30	1/50 " "	68	2 " "
33	1/25 " "	71	4 " "
37	1/10 " "		
40	1/5 " "		
44	1/2 " "		

CHAPTER XXVII

DESENSITIZING OF PHOTOGRAPHIC EMULSIONS

357. Use of Coloured Developers. Carey-Lea, as far back as 1877, showed that after immersing a photographic plate in ferrous oxalate developer it was possible, without risk of fog, to illuminate the darkroom much more brightly than would have been possible during the handling of the same plate when dry. This effect was attributed to the orange-red coloration of the developer, and little attention was paid to it, since the emulsions were so insensitive that in all cases a bright illumination could be used.

About 1889 various attempts were made to introduce into photographic practice the use of developers which had been coloured red by the addition of certain dyes, these dyes being subsequently destroyed in an acid fixing bath (coralline, croceine). The method, however, was not successful, since the dyes transmitted both blue and violet light. In 1900 A. and L. Lumière and A. Seyewetz, with the same object in view, recommended the use of an orange-coloured compound, magnesium picrate, which allows the development to be observed at a distance of about 18 in. from a candle or at about 5 ft from a 10-watt lamp, provided development is sufficiently rapid and the plate remains covered by a depth of developer of about $\frac{1}{4}$ in. If these distances are doubled, it is possible to remove the negative from the bath and examine it very quickly by transmitted light. This method of working, although it afforded interesting demonstrations, was not used in practice.

358. Loss in Sensitivity of Emulsions Impregnated with Developer. After the use of organic developing agents had become general, it was frequently pointed out that after the developing bath had thoroughly impregnated the emulsion a considerable lowering of sensitivity took place, which could not be explained in these cases by any coloration of the bath. In 1901 Lüppo-Cramer carried out some experiments in this direction (using the different developing agents) and discovered that this action occurred with nearly all the most common developers (with the exception of hydroquinone), both in plain and alkaline solutions, and that sulphite tended to reduce the effect. In 1920 the same worker found a very marked reduction in the sensitivity

of photographic emulsions (reduced to $\frac{1}{50}$ th or $\frac{1}{100}$ th of the original value) after they had been bathed for about 1 minute in a pure solution of diaminophenol-hydrochloride of from 0.02 to 0.05 per cent strength, although no reduction in the latent image resulted from this treatment. An analogous effect may be obtained by the addition of this product to a hydroquinone developer; it was soon recognized that this *desensitizing* was due to traces of oxidation products, which are rapidly formed by the action of the air on dilute solutions of this developer.

It has since been recognized that ferrous oxalate developer is also a very efficient desensitizer.

359. Desensitizers. During further experiments on this phenomenon, Lüppo-Cramer discovered, several months later, the remarkable desensitizing properties of phenosafranine, a violet-red dye of considerable colouring power.

It was soon shown that the desensitizing properties of phenosafranine are possessed by various safranines and, in varying degree, by different substances of similar constitution. The red colour of some of these substances might lead to the supposition that the protection from fog is due to the absorption of the active radiations by the dye impregnating the emulsion. This is not the case, however, for the efficiency of these desensitizers is practically as great with panchromatic as with ordinary emulsions, and, secondly, a sensitive plate exposed behind a cell containing a solution of the dye, even in concentration greater than that used for desensitization, and under a layer of greater thickness than that of the developing bath, develops an intense fog. This is due to the fact that the red safranines absorb very little of the violet radiations. It was discovered not long afterwards that certain violet dyes belonging to the safranine family were capable of acting as efficient desensitizers.

The first experiments were carried out with 1:200 solutions, in which the sensitive plate was bathed for 1 minute. At the end of this time the darkroom may be illuminated as brightly as required, provided the blue and violet radiations are absorbed by a yellow or orange filter. A yellow light source of feeble

intensity, such as a candle or petrol flame, may be brought quite close to the dish in which the development is taking place, and it is even possible to examine the negative by transmitted light as frequently and for as long as required during the course of development.

Almost immediately it was shown that desensitizing could be brought about even with the much more dilute solutions of 1 : 20,000 and 1 : 50,000, so long as moderate intensity of illumination is observed in the darkroom, either as a bath before development or in the developer itself.

With either of the two methods of desensitizing, safranine prevents or reduces considerably the development fog, so that it is possible, when necessary, to extend development beyond the limits usually fixed by the growth of the fog, and also to use a much more alkaline developer. Finally, hydroquinone developer, which works somewhat slowly in the normal state, acquires almost the properties of a rapid developer, such as metol.

The only defect of safranine is its strong staining action, which causes a considerable coloration of the fingers (more particularly the nails) and of the gelatine, especially if it has been used in the concentrations which were first recommended. The coloration of the gelatine is removed for the most part during the subsequent manipulations and the washing, any defects in this last process being very clearly shown by the unequal coloration of the different parts of the plate. This coloration, however, even when it is fairly intense or irregular, does not affect printing adversely, and may therefore be ignored.

The most useful employment of desensitizing is emphatically with panchromatic plates.

All desensitizers are not, however, suited to all emulsions which are panchromatic, or sensitive to infra-red, probably owing to reactions between the colour sensitizers and the desensitizer. The effect of a given dye on a given emulsion varies greatly from one spectral region to another.

Many contradictions may be noted in publications on the properties of desensitizers owing to the use in experiments of impure or wrongly labelled products. A large number of substances which are energetic desensitizers in plain aqueous solutions are unusable in practice, the desensitization being annulled or decreased during development by the action of one or other of the components of the developer; tests of a desensitizer must therefore include a practical

development test in an abundance of yellow light (Miss F. M. Hamer, 1931).

360. The desensitizers are all weak oxidizers. They can destroy or considerably diminish the latent image in a solution containing also an acid and bromide, the silver formed by light being re-converted to silver bromide. This may be demonstrated (Lüppo-Cramer, 1924) in the following way. If a uniformly fogged plate is treated with a solution containing a desensitizer and potassium bromide and is then dried without rinsing, it will give, on subsequent exposure, a direct positive image because destruction of the latent image formed in the fogging exposure occurs where the plate receives a second exposure in the presence of the oxidizing desensitizer. This phenomenon is sometimes described as "sensitized Herschel effect" (§ 209).

On the other hand, it has been observed (Lüppo-Cramer, 1934) that, with certain rapid emulsions, an intensification of the latent image occurs when the desensitized emulsion is exposed to yellow or green light. Desensitization is not effective towards X-ray exposures.

The latent-image destruction that occurs on exposing the desensitized emulsion is brought about most efficiently by red and infra-red radiation, and for this reason it is unwise to use a red light for the inspection of desensitized material. Although a yellow safelight screen usually transmits red and infra-red light, the extension of the transmission into the yellow and green parts of the spectrum, to which the eye is relatively more sensitive, allows the total amount of light to be reduced, without inconvenience, so that the amount of red light transmitted becomes small.

Latent-image destruction occurs if there is a long delay between desensitization of the emulsion and its subsequent development.

The mechanism of desensitization has not yet been completely worked out. Many substances that act as desensitizers for silver bromide emulsions behave as sensitizers for silver-iodide emulsions (these silver-iodide emulsions being only of theoretical interest). Again, a number of cyanine dyes that are used in silver-bromide emulsions as sensitizers towards red light exert on the same emulsion a slight desensitizing action with respect to blue light. Certain substances that act as sensitizers are converted to desensitizers by the inclusion of a nitro ($-\text{NO}_2$) group in the molecule. It may be stated, however, that a substance

will act as a desensitizer only when it is adsorbed to the silver halide grain.

The investigations of V. Sihvonen (1928) and of E. Bauer (1928) on the mechanism of photochemical reactions lead to the view that the light energy received by the silver bromide is transferred to the desensitizer and that only the desensitizer is reduced. Under normal conditions the reduced desensitizer would be directly regenerated by atmospheric oxidation. This affords an explanation of why a very small quantity of desensitizer can protect a relatively large quantity of silver bromide during a prolonged exposure of low intensity, while the degree of protection is reduced for exposures of high intensity, and no protection at all is afforded in the absence of oxygen (M. Blau and M. Wambacher, 1934, and M. Blau, 1935), as, for example, in a high vacuum or in an inert atmosphere.

361. The discovery of desensitization led a number of experimenters to seek further desensitizers both among the compounds already known, especially those dyes whose chemical constitutions were similar to those of the safranines, and the desensitizing oxidation products of developers, and among new substances that were specially prepared.

Two inorganic substances have been found to have desensitizing properties, mercuric cyanide (H. Meyer and K. Walter, 1926) and iron nitrosulphide, $\text{NaFe}_4(\text{NO})_7\text{S}_9$ (J. Duclaux, 1935), but are of little practical interest. Mercuric cyanide causes an appreciable destruction of latent image and often gives rise to an intense fogging.

Besides the safranines, to which reference has already been made, a number of dyes were found to have desensitizing properties, for example, rhoduline red, auramine, chrysoidine, fuchsine (Lüppo-Cramer), methylene blue, etc. However, the desensitizing action is often accompanied by other, undesirable features which limit the practical value of the substance. The following list includes those desensitizers, which, as well as the safranines, have been found to be of practical use.

Aurania (A. and L. Lumière and A. Seyewetz, 1921) is one of the few desensitizers which can be added to a hydroquinone developer without precipitation. Its desensitizing action is not very powerful and, used at a concentration of 0.2 per cent, it stains the gelatine an orange-yellow colour. Care should be taken when using this desensitizer not to allow even a

dilute solution to come into contact with the skin since it has been found to cause dermatitis.

Pinacryptol Yellow was introduced in 1922 by R. Schuloff and E. Koenig. It consists of the methylsulphate of 1-methyl-2 (3-nitrostyryl)-6-ethoxyquinoline which yields a slightly coloured but non-staining solution. It is very energetic as a desensitizer, particularly when used with panchromatic plates, but it cannot be added to developers containing sulphite since this decomposes it.

Pinacryptol Green (B. Homolka, 1925), or 1:3-diamino-phenyldiazonium hydrochloride, a deep green solution that does not stain. As a desensitizer it is as effective as the safranines with respect to non-colour sensitive emulsions and is slightly better than the safranines for many panchromatic emulsions, but it gives rise to some veil even on developing in total darkness. It is not recommended for use when development is to be carried out in a very alkaline developer, in which case the gelatine becomes irregularly stained a deep grey colour. The solution of pinacryptol green should not be exposed to daylight.

Pina-white (B. Wendt, 1928) is a colourless desensitizer that is used in a concentration of 0.2 to 1 per cent usually together with 4 per cent sodium sulphite and 0.2 per cent potassium bromide. It consists of anthraquinone 1:7 disodium sulphonate. It is more active than safranine on panchromatic emulsions, and can be used in the developer without any precipitation. It sometimes gives rise to some veil.

Qualitol (J. D. Kendall, 1937) which is the methylidide of diquinalylethylene gives a slightly coloured solution that does not stain. It is a very efficient desensitizer for panchromatic emulsions and does not cause fog.

Among other sensitizers which have been described but which do not appear to have been made commercially are the azocyanines (F. M. Hamer, 1924) and the non-staining isophenosafranines (I. G. Farbenindustrie, 1927).

362. **Desensitizing Practice.** The inspection of an image during development is often considered desirable in order to alter the time of development when the brightness range of the subject is greater (or less) than average, or when doubt exists as to whether the exposure given in the camera was correct. However, the level of illumination permissible during the development of a panchromatic emulsion is quite inadequate to allow any useful examination of the image. Thus, it is only by desensi-

tizing that this inspection can be made possible. Desensitizing offers, moreover, the advantage that the possibility of the incidence of aerial fogging is reduced.

An ideal desensitizer should possess the following properties. It should completely remove the sensitivity of the silver bromide emulsion without attacking the latent image and without causing veil. It should be sufficiently soluble to allow a stock solution to be prepared, preferably without the aid of solvents. It should be stable both in the dry state and in solution, and its desensitizing power should not be appreciably reduced by the various chemicals usually found in developers. It should be compatible with the dye in the antihalation backing. The desensitizing solution should allow a large number of plates or films to be treated in succession and, after fixation the desensitizer should be readily removable by washing, hence it should not adsorb to gelatine. It should not be toxic and it should be readily obtainable at a reasonable price.

363. The term *desensitizing power* is applied to the ratio of the sensitivities of an emulsion measured before and after desensitization. This ratio varies according to the type of emulsion used and, for the same type of emulsion, according to the spectral value of the light used in making the measurement. For example, on treating in the same way different non-colour-sensitive plates O. Bloch (1933) found that the degree of desensitization increased as the average diameter of the emulsion grains became larger, the desensitizing power rising from 230 for a fine grain emulsion (average grain diameter 0.2μ) to 3,500 for a rapid, coarse-grained emulsion (average grain diameter 0.94μ). The oxidation products of developers usually have only a negligible influence on the colour sensitivity. Probably as the result of reactions between the colour sensitizing dye and the desensitizer, the effect of a given desensitizer often varies when used on panchromatic and infra-red plates of different manufacture, and the various desensitizers vary considerably in their effect on a given emulsion. The colour sensitivity is usually reduced more than the natural sensitivity. Thus under working conditions where, for a given panchromatic emulsion, the desensitizing power is about 100 for white light, it is possible to reach 1,000 in a particular spectral band.

For the same emulsion and the same desensitizer, the desensitizing power is approximately

proportional to the amount of the desensitizer adsorbed per unit area of the emulsion. The adsorption of the desensitizer to the surface of the silver bromide grains is shown by the fact that washing an emulsion after desensitizing decreases the desensitizing power but does not reduce it to unity. It has been found in one series of experiments that the desensitizing power increased from 3,500 to 6,000 when the time of immersion in the desensitizer was prolonged from 2 to 70 minutes. The increase in desensitizing power was very rapid at first and then, after 5 minutes, very slow. The use of a more concentrated solution allows the same result to be obtained in a shorter time of immersion, but it is still necessary for the desensitizer to penetrate right through the emulsion layer. The rate of desensitization is increased on raising the temperature and, on the other hand, it is decreased when the emulsion is strongly hardened.

Irregular results have been frequently obtained in desensitizing plates having an anti-halation underlayer containing manganese dioxide, or "self-screen" orthochromatic plates, by reason of a reaction between the desensitizer and the manganese dioxide or the acid dye constituent of the yellow filter embodied in the "self-screen" emulsion. Again, anomalous results have been found on developing desensitized plates and films when amidol is used for developing.

364. Desensitization may be carried out *before* or *during* development, the desensitizer being used in a pre-bath or added to the developer, providing that the desensitizer is compatible with the developer. It has been noted above that many desensitizers may not be added to developers containing a polyphenolic developing agent because of a more or less rapid precipitation, depending upon the concentrations of developer and desensitizer. The chemical fog that appears on plates, even when developed in total darkness, seems to be connected with the tendency of the desensitizer to precipitate and is, thus, always more intense when desensitizing is carried out during development than when it is effected by means of a pre-bath. At equal concentrations the desensitizing power is greater when the desensitizer is used in the developer than when it is used in a pre-bath, but it should be noted that the concentration should be considerably less in the former case. In many cases desensitization affects the activity of the developer and notably the shape of the

curve showing the value of gamma as a function of the time of development. The appearance of the image is usually more rapid, but the total development time is increased. T. H. James (1939) found that safranin and other basic dyes increase the rate of development in solutions containing developing agents whose speed of action is decreased by sulphite (e.g. hydroquinone, chlorhydroquinone, pyrogallol, glycin) and are without appreciable effect on developers whose action is accelerated by the addition of sulphite. In the case where the desensitization is carried out in a pre-bath, the fact that the emulsion is swollen with water tends to retard the appearance of the image.

Desensitization is in general ineffective on emulsions that are physically developed prior to fixation (§ 484). Probably the desensitizer adsorbed to the silver bromide is displaced by the soluble silver salt contained in the physical developer.

365. Desensitization may be carried out either by a light that is safe for the material being used or, preferably, in total darkness. The light that is to be used for inspecting the desensitized plate should not be turned on for at least two minutes. Five minutes' desensitizing should be given in the case of very rapid panchromatic emulsions. Since these times are the least that may be given when the desensitizer is used in the developer, development in a rapid developer would already be far advanced by the time that the inspection light is turned on and this would reduce the effectiveness of the method in the case of a serious over-exposure. The light used for the inspection of the desensitized material should be green, bright yellow, orange, or light red. A green light should be avoided when using a red desensitizer and vice versa because in both cases the desensitized material would appear almost black.

In all cases where, for example, in order to reduce the danger of the formation of air-bells, the sensitive material is pre-soaked before development the desensitizer may be added to the pre-bath. It has been suggested (K. Wiebking, 1921) that the desensitizer be incor-

porated in an anti-halation backing layer which would dissolve in the first solution into which the plate or film is placed.

The desensitizer is dissolved to make a stock solution that may be diluted according to requirements. The formation of moulds in the dye solutions can be avoided by the addition of a very small amount of disinfectant, such as Sunoxol, that would be harmless to the developer or to the emulsion in the very small concentration that is used. For example, a dye desensitizer for use as a preliminary bath at a concentration of 1:5,000 may be made by diluting one part of the following stock solution with 24 parts of water--

Water to make	.	.	1000 ml
Desensitizer	.	.	.5 g
Sunoxol	.	.	1-2 ml

The desensitizing bath may be repeatedly used. It should be filtered to remove any solid matter that accumulates, e.g. dust, deposit from hard water, and, in the case of pinacryptol green, a deposit formed by the coagulation of a part of the dye by potassium bromide dissolved from the desensitized plate. This solid matter, if it is not removed, will cause spots where particles adhere to the emulsion. The bath may be maintained at almost constant activity for quite a long time by topping it up to a constant level with a solution that is slightly more concentrated than the initial bath.

There is no point in rinsing the desensitized plates or films before transferring them to the developer.

Various ways have been suggested for the removal of the red safranin stain that remains in the gelatine after fixing and washing, a step that is usually unnecessary. However, one can bathe the film or plate in dilute (1 per cent) nitric acid or, better, in the coldest possible 1 per cent solution of sodium nitrite containing about 1 per cent hydrochloric acid. In this latter case the safranin is converted to a violet diazonium compound that can be readily washed away. This treatment causes a slight reduction of the image that is, however, usually imperceptible.

CHAPTER XXVIII

THE DEVELOPMENT OF THE NEGATIVE IMAGE

366. Physical and Chemical Development. Physical development, exclusively used for wet collodion plates, has never been generally used for gelatine-bromide emulsions. It is used occasionally for scientific purposes, and there has lately been some interest in the method for obtaining miniature negatives of very low granularity.

Chemical development in a solution of pyrogallol made alkaline by the addition of ammonia or by an alkali carbonate, used first in 1862 for dry collodion plates, has been used for gelatine-bromide dry plates since their first appearance. Subsequently, ferrous oxalate (Carey-Lea, 1877) became frequently used in the early days of organic developers.

In physical development, which involves a homogeneous chemical reaction, the developing agent reduces a soluble silver salt that is added to the developer, and the silver that is formed is deposited on the latent image nuclei, usually in a light-grey form. The silver halide grains of the emulsion take no important part in the development which can be carried out after fixation, if desired, i.e. after the removal of the silver halide.

In chemical development, which involves a heterogeneous reaction, the silver bromide of the grains that are affected by the light is reduced *in situ*. The silver grain that is formed usually appears black by virtue of its porous structure. The structure of the developed grain has been compared with that of a lump of coke, but photomicrographs made with the aid of the electron-microscope (Hall and Schoen) have shown that the chemically developed grain consists of a tangled mass of very fine silver ribbons that is often referred to as "seaweed." In normal development the filamentary particle of silver is confined within the mould that the original silver halide grain formed within the gelatine and hence when viewed at the ordinary power of the optical microscope the developed grain usually seems to preserve the shape of the undeveloped grain. The developers used for the chemical development usually contain a silver halide solvent. Thus, unless the chemical development is rapid, part of the silver halide from the emulsion dissolves in the developer with the result that the

image will be formed partly by physical development. The silver that is reduced from the developer is deposited on the walls of the tank or dish and forms a fine sludge that settles slowly on the bottom of the vessel.

367. The developer is always, in the chemical sense of the term, a reducing agent. But not all reducing agents can be used as developers. Some reducing agents would indiscriminately convert the exposed and unexposed silver halide grains to silver, while others, on the other hand, would not be sufficiently powerful to act even on the exposed grains. Within the limits of *reduction potential* between which a reducer may be employed as a developer, the degree of exposure of the grain has an influence. Grains which received only a small exposure can be developed by the more energetic developers but not by those of higher (i.e. less reducing) potential. Similarly, the developing solutions that may be prepared starting with the same developing agent can show appreciable differences in their action depending upon their composition, concentration, and temperature.

If the emulsion speed of a material is determined by exposing a number of sensitometric wedges under identical conditions, and developing them in different developers, it is generally found that, in a given developer used at constant temperature, the value of the speed increases at first with the time of development. The speed passes through a maximum at an optimum value of the gamma, and then decreases on greatly prolonging the time of processing. When a number of films or plates are successively developed in a limited volume of developer, the maximum emulsion speed steadily decreases even though the time of development is increased so as to obtain the same gamma value each time. The maximum speed values obtained in different developing solutions using the same developing agent vary considerably, but the variations are even greater when different developing agents are compared, and, above all, when the speeds obtained by chemical development are compared with those obtained by physical development.

In order to illustrate this point, and although the numerical values are only valid for the actual emulsion used (a slow, lantern-slide emulsion),

the relative values of the maximum speed obtained by E. R. Bullock (1927) in various developers are given in the following table.

Chemical Development	
Metol	2-4
Amidol	1-9
Metol-hydroquinone (1 : 1)	1-5
Metol-hydroquinone (1 : 2)	1-5
Paraminophenol	1-3
Hydroquinone	1-1
Ferrous oxalate	1-0
Glycin	0-9
Pyrogallol	0-7

Physical Development before Fixing	
Metol (after iodizing)	0-4
Metol (without iodizing)	0-2
Hydroquinone	0-16

Physical Development after Fixing	
Metol in acid solution	0-2
Paraphenylenediamine in sulphite solution	0-19

A similar comparison, made only for the chemical development of some rapid emulsions (Luppo-Cramer, 1921) gave the following result.

Glycin	1-0
Metol-hydroquinone	1-75-2-1

368. A number of experimenters (notably K. Schaum and V. Bellach, 1901, S. E. Sheppard and C. E. K. Mees, 1906, W. Scheffer, 1907, M. B. Hodgson, 1917, T. Svedberg, 1922, L. F. Davidson, 1925, W. Meidinger, 1935) have attempted to follow, under the microscope, the course of the chemical development of emulsion grains. Cine-photomicrographs of developing grains have also been made (C. Tuttle, E. P. Wightman, and A. P. H. Trivelli, 1927, and H. Frieser, 1939). A certain delay is found between the instant that the developer reaches the grain and the time that the development sets in. This delay is known as the *induction period*. The grain darkens at first at a few points (latent-image silver specks, corresponding generally to the locations of the sensitivity specks) on the surface of the grain. Development spreads from these points until the whole grain becomes blackened. Fig. 28.1, after Hodgson, shows the appearance of some grains at various stages of their development. The magnification is about $\times 1,350$ diameters. Some grains would not develop, whatever the exposure. Any one grain could either be entirely developable or entirely non-developable. However, the entirely developable grains were not always completely developed at the instant of stopping the development.

During development the grains more or less swell out, more so as the energy of the developer is increased. Grains developed in a developer of feeble reduction potential are more compact and exceed the volume of the initial crystal less



FIG. 28.1. SILVER BROMIDE GRAINS AT VARIOUS STAGES OF DEVELOPMENT

than those that are developed in a solution of higher reduction potential. In a very dilute metol-hydroquinone developer the structure of the developed grain is sufficiently open to transmit light, because of the filamentary structure referred to above. When development is carried out by paraphenylenediamine it is to a large extent physical because of the marked solvent action of this agent on silver bromide, and the reduced silver forms compact, crystalline plates. The swelling of grains on the energetic development of an emulsion layer having the usual concentration of silver bromide results frequently in a clumping together of neighbouring grains, thus increasing the granularity of the image.

In developers containing a silver-halide solvent, and particularly in those developers containing a high concentration of sulphite, the non-developable grains, especially the smaller grains which are known to be less sensitive, dissolve and the silver resulting from the reduction of the soluble silver complex is deposited on the grains in the course of development. The deformations of the developed grains are due partly to this effect and partly to forces exerted by the gelatine.

369. In a given developer, the grains all develop in approximately the same time once

development has set in. But the development sets in only after an induction period that is greater for smaller exposures to light. However, the induction period is also considerable in the region of solarization. The average time of development of the individual grains increases as the developer is diluted.

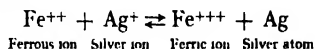
As a result of the existence of this variation in the initial phase of development between grains belonging to different parts of the image, the size of the grains, when development is stopped at a low gamma, represents a fraction of the size of the parent silver halide grain; the size of the fraction depends upon the degree of exposure. For example, in an experiment of Sheppard and Mees on a step-wedge developed in dilute ferrous oxalate developer, the mean diameter of the grains was 1.01μ in the step that had received an exposure of 1 metre-candle-second, and was 1.82μ in the step that received 22 metre-candle-seconds. This difference decreased as development was more prolonged. The mean diameter of the developed grains becomes independent of exposure when development is carried out until gamma infinity is reached.

When development is stopped at an intermediate value of gamma the grains are finer in the depths of the emulsion layer than on the surface, these lower grains having been reached by the developer having to diffuse to the greater depth. When the gamma value is a maximum, i.e. at gamma infinity, no difference is found between grains on the surface or in depth.

The number of grains developed per unit area of the emulsion layer increases with the exposure (except in the region of solarization) and is approximately proportional to the resulting density.

370. The shape and size of the silver grains that make up a physically developed image bear no relation to the shape and size of the parent silver halide crystals. The induction period is negligible when compared with the total developing time, and the final size of the silver grains depends only upon the time of deposition of silver, this size being the same for both fine- and coarse-grained emulsions (A. and L. Lumière and A. Seyewetz, 1924). At the start of development the silver particles are so small that neither their shape nor their size can be determined. Later, they are found to consist of hexagonal crystalline tablets. On extending development up to 48 hours, the diameter of the crystals can reach 2.5μ in paraphenylenediamine (the bath changed every hour) used after fixation.

371. **Reduction-oxidation Potentials.** In the most general sense of the term, the *oxidation* of an ion (§ 293) means the increase of its positive charge, while *reduction* refers to the inverse phenomenon. For example, the oxidation of ferrous to ferric ions involves the transfer of an electric charge of 96,490 coulombs for each gramme equivalent. This oxidation may be effected by oxygen or by a substance that can act as a source of oxygen, but it can also be effected without the intervention of oxygen, the requisite charge being accepted by silver ions which are then converted into neutral atoms of silver. This last reaction is reversible, in the sense that an atom of silver can give up an electron (negative charge) to a ferric ion, becoming a silver ion in the process—



Readers who are not acquainted with the terminology of electro-chemistry should note that in equations of this type the positive signs indicate, according to their number, the *lack* of negative charges (i.e. electrons). Positive charges cannot be transferred from one ion to another because they belong to the atomic nuclei. It is the electrons, or negative charges, that are transferred leaving behind a greater net positive charge on the oxidized ion.

Imagine that a voltaic cell is set up using two liquids, a partially oxidized ferrous solution and a dilute solution of potassium bromide saturated with silver bromide, these being separated by a porous membrane. A platinum electrode is placed in the iron solution and a silver electrode is placed in the other. The electro-motive force, E.M.F., of this cell would be the difference between the electrical potentials that exist between each electrode and its electrolyte, that is, between the silver and the solution of silver bromide on the one hand (E_{Ag}) and between the platinum electrode and the solution of the reducer (E_{Red}) on the other. If E_{Ag} is greater than E_{Red} a current would flow from the platinum electrode to the silver electrode if they were connected by a wire and silver ions would be reduced to silver in one compartment and some of the ferrous salt would be oxidized to ferric salt in the other.

Such a cell is never set up in reality. The two half-cells are compared, separately and in turn, with a standard reference half-cell to which is arbitrarily assigned a zero potential in much the same way as one refers to the temperature of melting ice as being zero degrees on the

Centigrade scale. The standard reference electrode, to which the potentials of other electrodes are referred, is the hydrogen electrode, consisting of platinum in contact with hydrogen gas. The potential of any real or imaginary cell would be the difference, therefore, between the potentials (referred to the hydrogen electrode) of its two electrodes.

The value of E_{Ag} thus measured at 18°C in a 0.01 N solution of potassium bromide, i.e. 0.119 per cent which is about the concentration usually found in developers, is 0.202 volts.

In order that in this case the silver bromide should become reduced to silver it is necessary that the potential E_{Ag} should be greater than E_{Red} , or in other words the reduction-oxidation potential E_{Red} of the platinum electrode in the solution of the reducer should be lower (more negative) than 0.202 volt. The reduction-oxidation potential of a solution depends upon the relative concentrations of the reduced and oxidized forms according to the following equation—

$$E_{Red} = E_0 - \frac{0.058}{n} \log_{10} \frac{(\text{Red.})}{(\text{Ox.})}$$

which is valid at 18°C. Red. and Ox. represent approximately the concentrations of the reduced and oxidized forms and n represents the number of electrons transferred on oxidation or reduction. In the case of the ferrous-ferric solution $n = 1$. Finally, this equation given for the reduction-oxidation potential holds only when the system is not affected by a change in pH.

372. Using mixtures of ferrous and ferric citrates and malonates, in the presence of 0.01 N potassium bromide, whose reduction-oxidation potentials (E_{Red}) were at various values between 0.10 to 0.60 volt, W. Reinders (1934) found that a partially developed photographic image continued to develop in a solution for which E_{Red} was less than 0.2 volt, the difference $E_{Ag} - E_{Red}$ being, of course, positive. When E_{Ag} was equal to E_{Red} the partially developed image was unaffected. However, when E_{Red} was greater than E_{Ag} the partially developed silver image was partly reconverted to silver bromide.

Those parts of the test strips which had not received any preliminary development were bathed in the ferrous-ferric solutions and only developed in those solutions whose reduction-oxidation potentials were below 0.110 volts, at which value $E_{Ag} - E_{Red} = 0.090$ volt.

The curves of Fig. 28.2 show the results obtained. Some pieces of the same film had been uniformly exposed so that under normal conditions the developed density would have been about 3.0. The pieces of film were developed for a short time in an energetic developer so as to obtain a density of 0.82. The strips were bathed for 20 hours in the experimental ferrous-ferric solutions, after which they were fixed. The curves show (I) the densities of the areas of the pieces which had received the preliminary

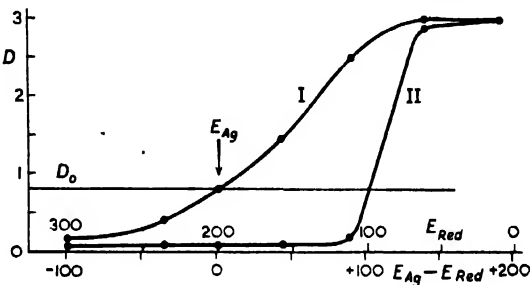


FIG. 28.2. EFFECT OF THE REDUCTION-OXIDATION POTENTIAL OF THE DEVELOPER ON PARTLY DEVELOPED IMAGE (I) AND ON EXPOSED BUT UNDEVELOPED EMULSION (II)

development and (II) the density of the area, on each strip, that was treated only with the ferrous-ferric solutions.

373. In order to start development of a latent image on normally exposed silver bromide, the E.M.F., represented by $E_{Ag} - E_{Red}$, must be positive and greater than a certain critical value of approximately 0.09 volt, or greater when the exposure was very small. The solubility of small particles of silver increases when the dimensions of the particles decrease and a solution which is in equilibrium with large silver grains can attack agglomerates of only a few atoms. In order that silver may be deposited upon the latent image it is necessary to increase the value of $E_{Ag} - E_{Red}$ considerably beyond the level for which the solution is in equilibrium with the relatively large grains of the developed image.

M. Abribat (1935) found experimental evidence that solutions of all organic and inorganic reducers whose reduction-oxidation potentials were below this limit (0.1 volt) were developers. He was thus able to develop images, though often of poor quality, in such widely diverse solutions as; culture of anaerobic bacilli, old red Burgundy wine, resorcinol partially oxidized by ferricyanide, leuco-bases of various dyes, and other

substances mentioned in the literature as having suitable reduction potentials.

A consideration of reduction potentials provides an explanation why silver-iodide emulsions are not developable in normal developers and why these developers must be restrained, by decreasing their effective reduction potential by the addition of potassium bromide, when they are to be used with silver chloride emulsions. The potential E_{Ag} of silver metal in contact with a 0.01 N solution of soluble halide saturated with silver ions is -0.023 volt in the case of potassium iodide and 0.24 volt in the case of potassium chloride. A ferrous developer that could just develop a latent image on silver bromide in the presence of 0.01 N potassium bromide would, as was mentioned above, have a reduction-oxidation potential of 0.1 volt. Since this potential is greater than the E_{Ag} for the iodide system, such a developer could not develop silver iodide under the conditions stated because its potential would be too high. On the other hand its potential would be rather low for the development of a silver chloride emulsion and in this case an increased concentration of potassium bromide acts as a restrainer, limiting the indiscriminate reduction of silver chloride grains by decreasing E_{Ag} according to the equation (18°C)—

$$E_{Ag} = (0.086 - 0.058 \log_{10} [Br^-])$$

where $[Br^-]$ represents the concentration of bromide in the solution.

J. Rzymkowski (1943) found that a solution of sodium anthraquinone-2-sulphonate at $pH = 5$ would act as a developer for silver iodide emulsions but that it indiscriminately reduced both exposed and unexposed silver bromide grains unless the pH was further lowered.

374. These ideas are only rigorously applicable to oxidation-reduction systems that are reversible and in equilibrium, conditions which were closely approached in the work of Reinders that was described above. These conditions are not usually met with in the case of developers compounded from organic developing agents. The direct measurement of the reduction-oxidation potentials of such developers is difficult (A. E. Cameron, 1939). In these cases it is necessary to take account of the effect on the system of the pH of the solution.

If an organic developing agent acts as a bivalent ion, as is most common, and supposing that the concentration of the ions remains constant during the action, the E.M.F. of the

system may be approximately given by the equation—

$$E_{Ag} - E_{Red} = 0.086 - 0.058 \log_{10} [Br^-] - E_0 \\ + 0.029 \log_{10} \frac{(\text{Red.})}{(\text{Ox.})} + 0.058 pH$$

where the value of the constant term E_0 depends upon the developer used.

It will be seen that, as in the preceding case, the E.M.F. is decreased when the concentration of bromide in the developer is increased. The E.M.F. is increased by an increase in the pH value. It should be noted that the E.M.F. depends not upon the absolute concentrations of the components of the solution, but upon the relative concentrations. Thus there is no direct correlation between its value and the speed of development in practice.

At equal reduction potentials, the ability of a developing solution to reveal details in the shadows of the image is independent of the developing agent used. V. Veidenbach (1934) established the equivalence of metol and para-aminophenol in this respect in developers also containing hydroquinone, by suitable adjustment of the alkalinity; he used metol at $pH = 9.6$ and para-aminophenol at $pH = 10.15$.

At equal values of pH , two alkalis may be interchanged in a negative developer without affecting the properties of the fresh solution (H. Faerman and N. N. Schischkina, 1933). In positive developers, or in contrasty developers, at high pH values, a close relationship is not always found between the pH and the activity of the bath (J. G. Stott, 1942).

375. Similar considerations have been applied to physical development by W. Reinders and M. C. F. Beukers (1939). The supersaturation of a developer with nascent silver is proportional to the difference $E_{Ag} - E_{Red}$ between the potentials of the silver and the developer. If Ag represents the concentration of silver in the supersaturated solution and Ag_0 the normal solubility of silver—

$$E_{Ag} - E_{Red} = 0.058 \log_{10} \frac{Ag}{Ag_0}$$

It should be noted that when the silver salt dissolved in the developer is not in the form of a complex, and the concentrations of bromide ions $[Br^-]$ is extremely small, the potential E_{Ag} is then much greater than in the case of chemical development.

In order to ensure that the reduced silver is deposited smoothly the value $E_{Ag} - E_{Red}$ should

not be too high. This value may be decreased by adding a substance that will form a complex with the silver ions thus reducing A_g and E_{Ag} , or by adding an acid to the solution, thus increasing E_{Red} .

376. The Mechanism of Development. The thermodynamical considerations that were discussed above throw some light on certain aspects of the chemistry of development, but they provide no information about the intermediate stages, or the mechanism, of the reaction. The first explanation of chemical development (W. Ostwald, 1893) held that silver ions, resulting from the dissolving of silver bromide by the developer, are reduced in solution in the immediate vicinity of the grains and the silver atoms that are formed are deposited on the latent-image nuclei. This theory was generally accepted until recently. Meanwhile, however, Volmer (1921) had objected to this theory on the ground that, for example, in order to develop a 9×12 cm plate to a density of about 1.0 it would be necessary to dissolve about 20 mg of silver bromide in a few minutes, which can scarcely be the case in view of the low solubility of silver bromide. T. H. James (1939) has established that the Ostwald mechanism is contradictory to observations made on the speed of development on the one hand, and the rate of reduction of silver ions on the other. In fact the rate of reduction of silver is neither proportional to the rate of solution of the silver halide into the developer, nor to the rate of reduction of the dissolved silver ions, nor to some product of these rates. Thus the development can result only from a reaction between the developer and the solid silver halide.

The reduction of silver ions from solution does, however, play a very small part in the formation of the photographic image when the developer contains a silver bromide solvent, but is only secondary to the chemical development proper.

377. The most commonly accepted theory is derived from a suggestion put forward by S. E. Sheppard and G. Meyer (1919) according to which the organic developing agent becomes adsorbed on the grains, and the silver of the latent image catalyses the reduction of the silver bromide. Various attempts that have been made to find experimental evidence of this selective adsorption have failed. A. J. Rabinovitch (1927-35) has modified this theory, holding that the developer is adsorbed, not by the silver halide, but by the latent-image silver, but the experiments upon which the

hypothesis is based are not convincing. In the most usual case, in which the developing agents act in the form of negatively charged ions, such an adsorption would be hindered (G. Schwarz, 1934) by the negative charge that exists on the surface of the grains by virtue of the excess of bromide ions that are adsorbed to the silver bromide crystals during their formation, these bromide ions forming a continuous sheath around the crystal, except over the silver latent image speck.

The experiments of T. H. James (1939-45) have clearly established the fact that development is a reaction that is catalysed by metallic silver and which, starting with the silver ions of the crystal lattice that are in contact with the latent-image silver, is extended along the borders of the silver that is formed by the development. The developer ions can approach the grain where the speck of latent-image silver has decreased the negative charge barrier.

It should be noted that physical development is also a reaction that is catalysed by silver, the reduction of the silver ions from solution being preceded by their adsorption on the latent-image nuclei or on the already partially developed image.

The negative charge on the grains is reduced by the oxidation products of developers (H. Staude, 1939) and by basic dyes whose positive ions neutralize the negative charge of the bromide ions. Again, the negative charge is always reduced in emulsions that have been colour-sensitized by dyes of the cyanine type.

378. Quantitative Laws of Development. At the instant that development sets in, the rate of the reaction is very great. The rate of development is thus chiefly controlled by the smaller rates of diffusion of the developer up to the developing grains in the layer of gelatine and of the opposite diffusion of the oxidation products of the developer.

At any moment the rate of development (the rate of growth of the density) in the usual developers is approximately proportional to the number of undeveloped grains remaining in the area of the emulsion under consideration. It is thus proportional to the difference between the maximum density D_∞ that would be reached after a very long development, and the actual density D —

$$V = K (D_\infty - D),$$

the coefficient K , called the *rate constant*, depending on both the emulsion and the developer.

Other things being equal, K decreases slowly in proportion to the age of the sensitive material. Sheppard and Mees (1907) found that, in the course of a series of experiments, for plates of the same batch, K decreased in 6 months from 0.0203 to 0.0100. K varies from one brand to another, and from one batch to another of the same brand. Finally the rate constant varies from one developer to another and, for the same developer, it is proportional to the concentration of the active ions.

In the course of experiments on ferrous oxalate at different concentrations, and on glycin developers with varying potassium carbonate content, A. von Hübl (1901) noted that the rate of development is proportional to the conductivity of the developer. This finding is in good agreement with the fact, already mentioned, that alkalis may be interchanged at equal pH values.

379. The Induction Period. The curves that show the growth of density as a function of the time of development of a batch of emulsion that has received a given exposure can be classified into four types. The shape of the curves in each type depends not upon the chemical nature of the developing agent, but on the electrical charge on the active species which may be either a neutral molecule or a single-, double-, or treble-charged ion (T. H. James, 1939).

In the case of the phenylenediamines, which act as the neutral molecule, the rate of development is a maximum at the start of development and decreases as the time of development is extended. The curve is always concave towards the time axis.

In development by the aminophenol developers (metol, paraminophenol, paraminophenylglycin and by hydroxylamine, all of which act in the form of single-charged ions, the rate of development rapidly increases to a maximum and then remains constant for a considerable period before ultimately decreasing.

In the case of development by agents that act in the form of double-charged ions, e.g. hydroquinone, pyrogallol, ferrous oxalate, glycin, and metolsulphonate, the rate of development is extremely small at the outset, and increases rapidly only after a considerable delay.

Hydroquinonesulphonate, which gives a treble-charged developing ion, acts similarly to the hydroquinone group, but gives a much greater induction period.

The absence of an induction period in development by the phenylenediamines is unaffected by

the addition of soluble bromide to the developer. However, in the case of the other developers the induction period is increased by the addition of bromide, the increase being more marked as the negativity of the active species is greater. The appearance of the induction period is due to the negative charge barrier, the magnitude of which has been estimated as 0.1 volt, that surrounds each silver bromide grain as the result of the adsorption of excess bromide ions to the crystal surface. This negative barrier tends to repel negatively charged developer ions with a force proportional to the charge on the ion. Only those ions whose energy is sufficiently in excess of the average value can penetrate the barrier, which is smaller in the vicinity of the latent-image speck, at the start of development. As development proceeds the latent-image speck grows, thus locally reducing the potential of the barrier and admitting a greater number of developer ions. Thus development will be an auto-accelerating process for negatively charged developer ions and an induction period will appear.

Another negatively charged zone surrounds each grain by virtue of the fact that the gelatine layer that is adsorbed to the grain carries a net negative charge when immersed in solutions of pH greater than the *isoelectric point*, which is the usual case in practical development.

The induction period becomes shorter as the exposure, and the size of the latent image, is increased.

If two parts of the same emulsion layer are exposed, part A at low intensity for a long time and part B at high intensity for a short time, so that they give equal densities on development to γ_{∞} , it is found (J. Cabannes, 1928, and P. O. Hoffmann, 1935) that part A develops more rapidly than part B .

380. The equation given in § 378 may be stated in the following forms—

$$\log (D_{\infty} - D) = \log D_{\infty} - 0.4343 K (t - t_0)$$

$$\log (\gamma_{\infty} - \gamma) = \log \gamma_{\infty} - 0.4343 K (t - t_0)$$

where t represents the duration of development and t_0 the length of the induction period.

When the induction period is negligible, as when the *Arithmetic Coefficient* (§ 381) of the developer is at least equal to 15, one can, using the second formula, calculate the values of K and γ_{∞} if the values of the gammas (γ_1 and γ_2) that are reached after times of development t_1 and t_2 such that $t_2 = 2t_1$, are known (S. E. Sheppard and C. E. K. Mees, 1907). Starting

from these values for K and γ_∞ the time of development required to reach any intermediate γ value can be calculated for the same developer and

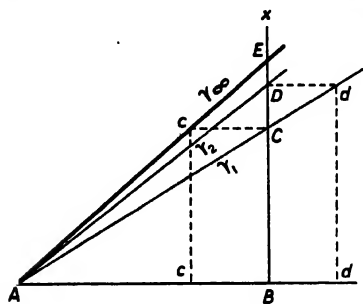


FIG. 28.3. GRAPHICAL CONSTRUCTION FOR γ_∞

for the same temperature from the following equations—

$$K = \frac{1}{t_1} \log_e \frac{\gamma_\infty}{\gamma_\infty - \gamma_1}$$

$$= \frac{\gamma_1}{1 - e^{-Kt_1}}$$

$$t_2 - t_1 = \frac{\log_e (\gamma_\infty - \gamma_1) - \log_e (\gamma_\infty - \gamma_2)}{K}$$

The same results may be obtained more simply by a graphical construction (W. Heydecker, 1925).

Finding γ_∞ . Mark off on a straight horizontal line a length AB (say 10.0 cm for convenience). At B erect a perpendicular and mark off lengths BC and BD proportional to γ_1 and γ_2 . Draw straight lines from A through C and D . From D draw a line parallel to AB to cut AC in d . Draw from C towards A a line Cc parallel to AB and equal in length to Dd . Draw a straight line from A through c to cut the gamma ordinate at E . The length BE gives the value of γ_∞ according to the scale adopted.

To find K . The value of K is given by the equation—

$$K = -2.302 \times \frac{\log_{10} (Bd/AB)}{t_1}$$

To find the time required to reach a given gamma. On the graph already used to find γ_∞ draw the line AF in which F fixes the desired value of γ . In the example in Fig. 28.4 the desired value of γ is taken as 1.0. Draw from F a line parallel to

BA to meet AE at f . The desired time of development is given by the equation.

$$t = -2.302 \frac{\log_{10} (fF/AB)}{K}$$

It must be emphasized that these relationships are only approximate. The most certain way to find experimentally the curve relating γ and t for the particular batch of films or plates by developing them in the chosen developer at the temperature at which it is proposed to operate.

381. The Arithmetic Coefficient of a Developer ; the Watkins Factor. The following rule was formulated by A. Watkins (1894) to provide a relationship between the time of appearance of the first details of the image (excepting the images of the sky and other obviously over-exposed highlights) and the total time of development that is required to give a desired gamma value. For the rule to be applied it is essential that the negative should have been properly exposed within reasonable limits and that the composition of the developer remains constant throughout the entire time of development. This last condition excludes developers containing am-

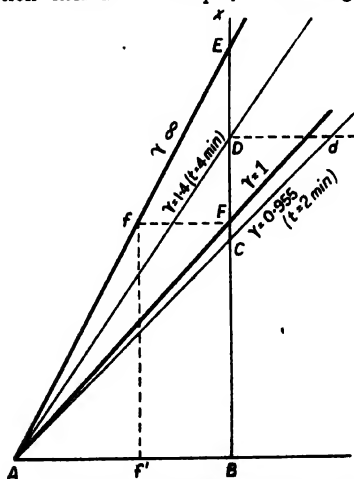


FIG. 28.4. GRAPHICAL DETERMINATION OF THE TIME OF DEVELOPMENT REQUIRED TO REACH A DESIRED GAMMA VALUE.

monia or other volatile ingredients, and plates or films that have been soaked in water or desensitizer prior to immersion in the developer.

The development time required to obtain a negative of a given gamma value is obtained by

multiplying the time of appearance of the image by a number which is practically constant and characteristic of each developer. This number, or *arithmetic coefficient*, is usually known as the *Watkins Factor*.

Although the Watkins factor is affected by the emulsion, by the temperature, and by the composition of the developer, it depends chiefly upon the developing agent used. Some inaccuracies are inevitable in its determination. Different observers assess the time of appearance of the image differently, and one observer repeating the experiment under other conditions of safe-lighting often obtains somewhat different results.

This method of development control is obviously applicable only to emulsions that can be developed by a bright safe-light, such as non-colour sensitive and orthochromatic materials.

382. The Watkins factor always has a greater value for developers for which the induction period is short or nil, than for developers that give a long induction period. Any circumstance that reduces the induction period, such as the addition of basic dyes or traces of iodide, increases the Watkins factor.

The values quoted for the Watkins factor relate usually to a gamma value of about 0.8.

<i>Developing agent</i>	<i>Watkins Factor</i>
Hydroquinone (with sodium carbonate) (the lower value applies to a strongly bromided solution)	from 5 to 7
Pyrogallol (the lower value corresponds to solutions having a high concentra- tion of pyrogallol and bromide)	from 4 to 18
Catechol (pyrocatechol)	10
Glycin (with potassium carbonate)	12
Paraminophenol	16
Amidol	18
Metol (with sodium carbonate)	30

For developers containing several developing agents, the Watkins factor may be approximately arrived at by taking an average per unit weight of the developing agent. For example if a developer contains, per litre, x grammes of metol and y grammes of glycin, the Watkins Factor for the compound developer would be roughly—

$$\text{W.F.} = \frac{(x \times 30) + (y \times 12)}{x + y}$$

This rule will not apply to developers that behave non-additively, for example metol-hydroquinone.

383. *The Various Causes of Fog.* Negatives are never entirely free from fog. The fog, or veil, may be caused by exposure to light, by

the storing of the sensitized materials under bad conditions, by the presence in the emulsion of spontaneously developable grains (*chemical fog*), or by the action of atmospheric oxygen on a developer-wetted emulsion (*aerial fog*).

The density in the shadows of the image that is found as a result of flare from the lens (§ 60) or in an amply exposed negative, is not counted as fog. An attempt to obtain almost zero density in the shadows of the image leads invariably to a loss of shadow detail because of the low gradient of the characteristic curve on the extreme toe.

384. *Chemical Fog.* All rapid emulsions contain a small proportion of developable grains (*latent fog*), which develop to a greater or less extent according to the composition of the developer. Examination under the microscope reveals some developed grains even in slow negative or positive emulsions that seem entirely free from fog.

It is often impossible to distinguish between development fog and latent fog because the latter appears only on development and both are likewise restrained by the same agencies.

It should be emphasized that rapid emulsions do not necessarily give the most dense fog, but the growth of fog on ageing (a fog which some authors have attributed to a very slow after-ripening) is often shown sooner on rapid than on slower emulsions.

The fog density is greatest in those areas of the emulsion that bear the least amount of image. Sometimes, in the case of an under-exposed emulsion that is also slightly fogged, the density of the shadow detail can be slightly lower than the fog density. It is well known that an unexposed plate always gives a greater degree of fog on development than a similar plate that has been exposed to light save on the area where the fog density is measured. These apparent anomalies are caused, as will be explained below in the section on development fog, by the soluble bromide, formed in the course of development of the image, retarding the growth of fog.

In order to reduce the tendency of old negative materials to give chemical fog, J. Traill Taylor (1891) recommended prolonged immersion in a dilute bichromate-sulphuric solution. This solution dissolves latent-image and sensitivity specks on the grain surfaces and the speed of the material is considerably reduced, even after rinsing, bathing in dilute bisulphite, washing and drying. Lüppo-Cramer (1923) found that all surface nuclei were destroyed on immersing

foggy plates and films for 3 minutes in a solution containing

Paraphenylenediamine hydrochloride . . .	1 g
Ammonium bromide . . .	25 g
Acetic acid, glacial . . .	12.5 ml
Water to . . .	1 litre

After washing and drying, the speed is much less reduced than by the bichromate treatment. The colour sensitivity is destroyed. This treatment does not destroy the internal latent image on exposed plates and these may be developed physically after iodizing or after fixing.

385. Development Fog. For each emulsion there is a critical time of development in a given developer, after which the unexposed grains start to develop. This critical time is reduced at higher temperatures and is increased by the addition of an anti-fogging agent. It is generally quite short for rapid negative emulsions though the rate of growth of fog is slow. On the other hand in the case of slow, contrasty emulsions, the fog appears only after a high gamma value has been reached, and then grows rapidly. In all cases this growth of fog makes it necessary to limit the time of development and often adversely affects the correct rendering of shadow detail.

The comparison of the tendencies of various emulsions to fog in a given developer, or the tendencies of the same emulsion to fog in various developers must always be made at equal values of gamma. It is generally found that the most energetic developers give the least fog. Thus there is no proportionality between the tendency to fog and the reduction potential. The ratio between the rates of growth of the image and the rate of growth of the fog has been called the *selectivity* (V. I. Shiberstoff, 1935) of the developer under consideration. This ratio varies from one sensitive material to another and with the temperature of the developer.

For each developer there is an optimum pH value at which its fogging tendency is least. Dilution retards the growth of fog much less than the growth of the image; thus the image is cleaner after development in a developer of moderate concentration than after development in a very dilute solution.

When an exposed emulsion has received prolonged development, the *covering power* of the silver is found to be lower for the fog than for the image. When development is extremely prolonged, there is formed in the non-image parts of the emulsion a dichroic fog which, intensified

by the deposition of silver by physical development, can become sufficiently dense to transform the negative into a positive (A. P. H. Trivelli and W. F. Smith, 1940).

Diverse observations indicate that the reduction of silver ions from solution in the developer plays a major role in the formation of fog. Among other factors the addition of a silver bromide solvent to the developer often increases the fog.

The presence in the developer of a number of impurities, particularly traces of tin salts (§ 278) or of sulphides (§ 410) will give rise to fog. The fogging influence of copper salts is reduced when the developer contains a relatively high concentration of sulphite. The very dense fog sometimes found in development by hydroquinone has been attributed by Rzymkowski (1928) to the action of an intermediate oxidation product.

386. Anti-fogging Agents. The presence of a soluble bromide in the developer inhibits the growth of fog more than that of the image. In fact, the bromide inhibits the formation of development nuclei on the unexposed grains. Once the nuclei of reduced silver are formed on the unexposed grains, their development, as fog, proceeds at the same rate as the development of the exposed grains (T. H. James, 1942). The fog-inhibiting influence of bromide is particularly effective in the case of developing agents of high reduction potential. However, large concentrations of bromide can increase the fog density, especially in pyrogallol developer.

Because of the fact that all emulsions are stabilized by potassium bromide which is imparted to the developer (except when a pre-bath is used), and that a soluble bromide results from the reduction of silver bromide, a used developer always contains more bromide than it did when fresh. The used developer also contains a trace of iodide, resulting from the simultaneous reduction of the silver iodide that is usually present in bromide emulsions. Most of the soluble iodide created in this way reacts at once with the undeveloped silver bromide forming silver iodide, while a very small proportion diffuses into the developer (M. L. Dundon and A. E. Ballard, 1930). This provides an explanation why a used developer gives less fog than a fresh developer containing the same, or a slightly greater, concentration of bromide.

Since the addition of bromide to a developer causes a loss in emulsion speed, especially in the case of developers having a low reduction

potential, there has been some attempt to replace it by other agents that do not decrease the sensitivity so much. Of the numerous agents that have been suggested the following may be mentioned: the thioanilides (S. E. Sheppard and E. Hudson, 1927); 6-nitrobenzimidazole nitrate (P. Wulff, 1927), which Trivelli and Jensen (1931) have shown to be effective in a concentration of 1:25,000, causing only a slight loss in speed, though it is unstable in a warm developer; the thioglycolic and thiolactic acids (O. Mathies and B. Wendt, 1928); aziminoparanitrobenzene (A. Seyewetz, 1932); metabenzylidenetherhodanine (G. Schwarz, 1935); various acetylenic substances including propargylic acid (W. Kleist, 1936) which are particularly active in very alkaline developers; and various indazole derivatives, for example, 5-nitroindazole or 5-aminoin-dazole hydrochloride (W. D. Peterson and R. M. Evans, 1939).

387. Aerial Fog. When a film or plate saturated with a developer containing hydroquinone is allowed to come into contact with air for some time during the course of development a dense fog may appear. This fogging was a particular nuisance in the development of roll-films and of cinematograph films that were wound on drums which dipped into a shallow trough of developer. It was suggested by E. Fuchs (1924) that this fog was caused by chemi-luminescence occurring during the oxidation of hydroquinone and for this reason could be overcome by desensitization.

The work of T. H. James established that this fog could not be attributed to chemi-luminescence because in this case the effect would be most marked on rapid emulsions, which was not the case. Neither could the fog be due to the formation of hydrogen peroxide in the course of the oxidation of the developing agent, another source which had been claimed. In order to obtain the same effect as that produced by the action of the air, the concentration of hydrogen peroxide in the developer would need to be many thousands of times greater than could be produced by the oxidation of the developer. The aerial fog appears to be caused by the formation of an unstable peroxide as an intermediate in the oxidation of hydroquinone. The formation of this fog is inhibited by desensitizers, the oxidation products of pyrogallol, and especially by ethylenediamine at a concentration of 0.03 per cent. The aerial fog is more severe when the developer is more alkaline. Its density varies with the sulphite concentration and is a maxi-

mum when the sulphite concentration is equal to that of the hydroquinone. It increases with the bromide concentration, and is considerably enhanced by thiocyanates and by traces of copper salts.

388. The Distribution of Fog in the Image. In many cases where it is desired to know the photographic density that has resulted from an exposure, e.g. to the image of a star, it is important to be able to differentiate between the density corresponding to the image proper and the fog density. The fog density is not uniform over all the densities of the image. The fact that on prolonging development the gamma passes through a maximum (γ_{∞}) and then decreases shows that the rate of growth of fog is greater in regions where the image density is lower. The rate of growth of fog is decreased in the higher image densities because of the greater concentration of exhausted developer, containing bromide and iodide and having a lower pH, that is formed in the vicinity of the already developed image grains. As a rough approximation the fog density at a given point in the image may be considered to decrease in proportion as the image density increases.

Various formulae have been proposed (R. B. Wilsey, 1925; S. E. Sheppard, 1926; H. A. Pritchard, 1928) in order to calculate what the densities of an image would have been in the complete absence of fog. The application of these methods of correction is somewhat involved and their validity has never been strictly established.

389. Effect of Dilution of the Developer. An extremely short development cannot be controlled and a developer must be the more dilute, the lower the gamma at which development is to be stopped. In a rapid developer, the value of the gamma increases very rapidly, especially at the start, and it is very difficult to stop development at a given gamma. Moreover, the development would continue to an appreciable extent even though the film or plate were placed in an acid stop bath after removal from the developer.

A. H. Nietz and R. A. Whitaker (1926) found that on diluting a highly concentrated developer, and increasing the time of development in proportion to the degree of dilution, the gamma values that were obtained first of all increased, passed through a maximum, and then steadily decreased.

In some developers the reduction of emulsion speed caused by bromide depends more upon the absolute concentration of the bromide rather than upon its proportion relative to the

other constituents of the solution. Thus the dilution of a bromided developer often tends to limit the loss in emulsion speed.

K. Chibisoff and V. Cheltzoff (1929) found that, on developing in each case to the same gamma, the emulsion speed was not affected by dilution. The drawbacks associated with the use of a very dilute developer are on the one hand an increased tendency of the bath to give development fog, and, on the other hand a rapid exhaustion. This exhaustion is, moreover, manifested locally in a very dilute, fresh bath by a depression of the higher densities. This results in a modification of the characteristic curve so that what would be the upper part of the straight-line portion in the case of normal development becomes rounded off into part of the shoulder. This effect of dilution is sometimes used with advantage in order to reduce the overall density range of the negative without adversely affecting the shadow details. The exhaustion of a diluted bath is particularly rapid when the bath is agitated vigorously in contact with air, or when the dilution is carried out using air-saturated water. When diluting solutions containing the usual organic developing agents, it is better to use a plain sulphite solution rather than water (McIntosh, 1899). In this way the salt concentration is not unduly diminished and this prevents the over-swelling of the gelatine that leads to reticulation.

P. C. Smethurst (1939) found that a developer containing a high concentration of sulphite, and made alkaline with trisodium phosphate, needed to be diluted between 5 to 10 times before the time of development was doubled. The ionization of the phosphate was depressed by the high concentration of sulphite and on dilution the pH of the solution would remain steady, or might even increase, before ultimately falling.

390. The Distribution of the Image in the Thickness of the Emulsion Layer. The same workers who made microscopical studies of the individual grains of a dilute emulsion (§ 196) have also studied the distribution of the grains of the image in the thickness of the emulsion layer. This distribution is affected by a number of factors among which are (a) the transparency of the emulsion layer with respect to the actinic light (b) the direction of the exposure, whether direct or through the support, (c) the ratio between the speeds of development and of penetration of the developer, (d) various treatments which can prevent the development of

the latent image in the surface layer of the emulsion.

After partial development, the depth to which the image extends into the emulsion is almost independent of the exposure. On increasing the degree of development, the thickness of the image approaches a maximum for each degree of exposure. The density continues to grow after the maximum thickness is reached. This maximum thickness increases as the exposure is increased, providing that the exposure does not become great enough for solarization to appear. S. E. Sheppard and C. E. K. Mees (1904) found that the thickness of the image on a step-wedge ranged from 15.8μ at a density of 0.20, to 26.5μ at a density of 0.76. Using a developer that was effective throughout the thickness of the emulsion layer, it was often found that some isolated large grains were found at a level deeper than the others, these more rapid grains having been affected by an exposure that was too small to cause the neighbouring grains to develop.

The distribution of the image in the thickness of the emulsion has a bearing on the action of bleaching, or photographic reducing solutions, particularly on those which act most on the surface layers of the emulsion (§§ 555-8). The same density can be obtained on two similarly exposed pieces of the same film, one piece being developed for a long time in a dilute developer and the other for a short time in a concentrated developer. In the first case the image is formed by the incomplete development of all the developable grains, and in the second case by the complete development of the grains in the surface layers of the emulsion. The average diameter of the grains, and thus the granularity, is less in the first case than in the second.

When an emulsion layer is exposed to X-rays, the latent image is uniformly distributed through the depth of the emulsion because of the high penetrating power of the radiation. In this case the distribution of the fully developed image does not depend upon the conditions of development.

Since gelatine strongly absorbs light in the far ultra-violet region of the spectrum, this radiation does not penetrate very deeply into the emulsion thickness. The degree of absorption increases as the wavelength decreases. Thus the maximum contrast obtainable on a given emulsion (at γ_{∞}) decreases with the wavelength of the light used.

In order to reduce the contrastiness of an emulsion, especially when making duplicates

in the motion picture industry, a blue-sensitive emulsion is used that is dyed yellow to limit the penetration of actinic light (J. G. Capstaff, 1924). Suitable dyes for this process, which will readily wash out, are tartrazine or naphthol yellow. The dye is applied by bathing the film in a 1 per cent solution of the dye, briefly rinsing and drying. Using such films, a further reduction in the contrast can be obtained by using ultra-violet light.

In the case of a plate or film that has been exposed through the support, the layers of the emulsion close to the support, and which received the greater exposures, are reached by developer that is already partially exhausted and loaded with bromide as a result of development of the surface grains. After an equal time of development in the same developer, a plate exposed through the support is less dense than a plate that is exposed directly, through a sheet of glass of the same thickness as the support, and the developed grains occupy a smaller thickness of the layer. The number of grains developed per unit area of the emulsion is less in the case of the emulsion exposed through the support. The image exposed through the support appears on the outer surface of the emulsion only in the most dense parts (S. E. Sheppard and C. E. K. Mees, 1904).

391. A method of *depth development*, that can be used in developing over-exposed negatives, has been described by G. Balagny (1903). A solution of amidol with sodium sulphite will develop normally, but on adding bisulphite to such a solution the image appears first in the layers of the emulsion close to the support and development spreads slowly towards the free surface of the emulsion but without reaching it. As the amidol solution diffuses through the emulsion, the gelatine, by virtue of its amphoteric character, reacts with some of the bisulphite ions, reducing the acidity of the solution sufficiently to allow it to develop in the depth of the layer.

A similar result was obtained in a different way by W. Kleist (1936) by saturating a caustic hydroquinone developer with acetylene. A small concentration of acetone was used to increase the solubility of the acetylene. When this solution was used, the silver bromide in the surface layers of the emulsion was rendered non-developable by conversion into silver acetylide.

S. E. Sheppard and C. E. K. Mees (1907) noted that development by solutions of organic developing agents is slowed down by the addition

of small quantities of thiosulphate, and they attributed this finding to development being confined chiefly to the depths of the emulsion. H. D. Murray and D. A. Spencer (1937) confirmed this view by comparing under the microscope the results obtained on yellow-dyed plates (§ 390) some of which were exposed normally, the others being exposed through the support. The silver bromide in the surface layers had been transformed into a non-developable complex. The same authors obtained analogous results by adding to the developer other salts that transformed the silver bromide into a difficultly developable form, for example potassium iodide or potassium cyanide. The effect of potassium iodide in this connexion provides an explanation of the influence of iodide in minimizing the appearance of abrasion marks (Lüppo-Cramer, 1914) since such marks are confined to the surface of the emulsion. Sodium thiosulphate, at a concentration of about 0.1 per cent, has been used for the same purpose.

392. The treatment of a plate or film, after exposure and before development by a very dilute solution of potassium bichromate, weakens the latent image and reduces the maximum gamma value (γ_m) that can be obtained (J. Sterry, 1904). This phenomenon, which is known as the *Sterry effect*, is sometimes applied when making copies with a material that is too contrasty for convenience (§ 676). If the bichromate solution is acidified or is used at a greater concentration, and is allowed to act for only a very short time, the latent image on the grain surfaces is entirely destroyed on the grains in the surface layers of the emulsion. The results are similar to those that would be obtained by using a surface-acting reducer on the developed image (S. E. Sheppard and C. E. K. Mees, 1907).

393. The Effect of Soluble Bromide on the Developer. In the early days of the gelatine-bromide emulsions the developers always needed a comparatively high concentration of bromide in order to retard the growth of fog. The subsequent improvements that have been made in the manufacture of these emulsions which are stabilized by the inclusion of a small amount of bromide, and the appearance of better developing agents, make it often useless to add bromide to the developer. It is important to keep the bromide concentration down to the minimum because of the loss in sensitivity that it causes. The full lines in Fig. 28.5 show the characteristic curves of a sensitive material developed for 2 and 8 minutes in a developer without bromide.

The broken lines show the characteristic curves for similarly exposed samples of the material developed for the same times in a part of the same developer after adding a moderate concentration of bromide. The dotted curves similarly show the effect of a high concentration of bromide. For each time of development the slope of the curve, determining the contrast, has not been altered by the addition of bromide. The

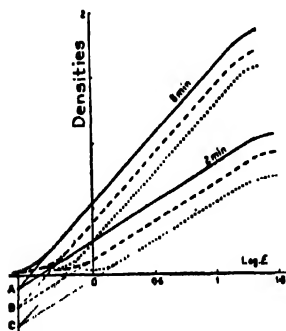


FIG 28.5. ACTION OF BROMIDE IN DEVELOPMENT

depression of the curves by the addition of bromide means that shadow detail that would be recorded on development in the bromide-free developer becomes lost, to a greater extent as the concentration of bromide is increased. Moreover, as the point (A, B, and C) about which the straight-line portions of the curves pivot, becomes further depressed, a greater loss of shadow detail will be suffered as the gamma at which development is terminated is lowered (*regression of the inertia*).

A. H. Nietz (1920) claimed that the depression of the points of intersection (A, B, C in Fig. 28.5) was proportional to the logarithm of the bromide concentration, and that the point of intersection was depressed perpendicularly. A. P. H. Trivelli and E. C. Jensen (1931) found that the depression was greater for X-ray exposures. This fact has been attributed to the more uniform distribution of the X-ray image through the depth of the emulsion, the deeper parts of the image being reached only by partially exhausted (more bromided) developer.

The induction period is usually increased on adding bromide to the developer.

If the development of a negative is started in a non-bromided developer and is continued in a bromided developer, or conversely, the results

are intermediate between those which would have been obtained had similarly exposed negatives been developed throughout, to the same gamma, in the bromided and non-bromided developers respectively. Thus, the effect of bromide is not permanent, as it would be if bromide partially destroyed the latent image (J. I. Crabtree, H. Parker, and H. D. Russell, 1933).

The use of a bromided developer often extends the range over which the brightnesses of the subject can be correctly reproduced by the sensitive material (W. Romer, 1934).

By preventing, or considerably retarding, the growth of fog, a comparatively high concentration of bromide in an energetic developer allows development to be pushed further than in a non-bromided developer, thus enabling the maximum contrast to be obtained when it is possible to sacrifice some emulsion speed, as, for example, in copying.

394. The various developing agents react differently towards the influence of soluble bromide. In the same way that the power of a vehicle can be judged by the effect of a rising gradient on its speed, so can the reduction potential of a developer be evaluated with sufficient accuracy for practical needs by the effect of a given concentration of bromide on its rate of development (R. Abegg, 1899; A. H. Nietz, 1922).

The influence of bromide has been attributed to a reversibility of the development reaction, a reversibility which, under the usual conditions of use, is only found in the case of ferrous solutions.

At the time when it was believed that chemical development proceeded by a reduction of silver bromide that had previously passed into solution in the developer, it was thought that soluble bromide acted by reducing the solubility of silver bromide in the developer. Later this theory became confined to the reduction of fog by bromide in the case in which the fog is due to physical development in addition to chemical development, (§ 366). The influence of soluble bromide is readily explained by the theory of development based upon the idea of oxidation-reduction potentials (§§ 371-5) and upon the adsorption of the developer to the silver bromide grains. On the one hand, by decreasing the reduction potential of the developer, the bromide increases the minimum size of the developable latent image, preventing the development of the less exposed grains (a mechanism suspected by G. Bredig in 1895), and on the other hand it

inhibits the adsorption of the developing agent (at least, if a negative ion) to the silver bromide grains.

Contrary to an opinion that is sometimes expressed, soluble chloride, no matter in what concentration, cannot be substituted for soluble bromide, even in the case of the development of silver chloride emulsions in the normal developers (E. Weyde, 1933).

All the effects found on adding soluble bromide to a developer are, obviously, also to be

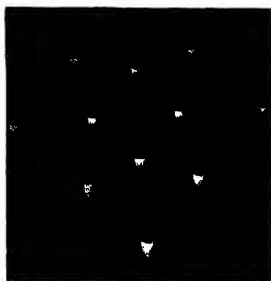


FIG 28.6. EFFECT OF BROMIDE GENERATED BY THE DEVELOPMENT PROCESS ON MOVING FILM (Streamers.)

observed in a used developer because its bromide concentration would be increased while the developing agent concentration would be decreased.

395. The Effect of Waste Products of Development. When the developer, that has been partially exhausted by the reduction of the silver halide in an exposed part of the emulsion, diffuses out of the gelatine it is denser than the surrounding solution and tends to descend vertically if it is not prevented from doing so by the agitation of the bath. These descending currents have been observed by following the movements of cotton fibres suspended in the solution (E. R. Bullock, 1922) and have been photographed directly (A. Haelsig and F. Luft, 1933). A simple experiment (J. I. Crabtree and C. E. Ives, 1926) shows the troublesome consequences of the streaming of partially exhausted developer. A plate was given a low, uniform exposure and was then heavily exposed behind a mask having a number of circular holes. The plate was then developed in a vertical position without agitation. The resulting image is shown in Fig. 28.6. The background density is reduced below each dense patch by the streaming of waste products which reduce the rate of development. An upwards streaming can be produced

when the emulsion has been soaked in water prior to immersion in the developer. In this case the exhaustion products will be carried upwards by the convection caused at the surface of the plate by the dilution of the developer by the water in the emulsion.

The streaming effect is greatest on emulsions that are rich in iodide. On the other hand, it is least on silver chloride emulsions (E. R. Bullock, 1922).

A used developer contains gelatine and gelatine degradation products formed by alkaline hydrolysis which give rise to foam when the bath is agitated. Furthermore, the presence of the gelatine, etc., may result in the infection of the bath by moulds and by bacteria which attack sulphite, converting it into sulphide which gives an intense fog.

396. When motion picture films were developed after being wound on a rectangular frame that was immersed, vertically, in the developer tank, various *rack marks* appeared on the developed film. The density was a maximum where the film passed over the top lateral member of the rack and decreased from the top to the bottom of each strand, being a minimum where the film passed under the bottom lateral of the rack.

Other irregularities due to the same cause are found on films developed on continuous processing machines in spite of the fact that the film moves through the bath at speeds of 25 to 200 feet per minute. The sensitometric strips, which usually consist of stepped exposures varying along the length of the film, and which are interposed between the rolls of film in order to assess the behaviour of the developer, give different characteristic curves according to whether the heaviest exposure precedes or follows the rest of the wedge (J. Crabtree and J. H. Waddell, 1933). On uniformly exposed films, a steady decrease in density can occur from the leading end of the film to the following end. These *directional effects* are particularly troublesome in the development of sound tracks for sound films by reason of the sound distortions to which they give rise.

Finally, the local turbulence, caused by the passage of developer through the perforation holes, tends to sweep away the partially used developer that is in contact with the emulsion, and thus accelerates development, resulting in a small region of increased density. Since the sound track lies very close to the perforation holes, this local non-uniformity of development

will be superimposed upon it and the defect emerges as an audible note when the processed track is finally run through the projector. This defect is called *perforation*, or *sprocket-hole modulation*.

These defects are avoided, or reduced to the point where they are negligible, by a sufficient agitation of the developer bath.

397. Border Effects. Other irregularities appear on images developed horizontally in a developer that is not agitated. Lateral diffusion within the emulsion layer of comparatively exhausted developer from a region of high density to an adjacent one of lower density, and of comparatively fresh developer in the reverse direction, results in the formation at the boundary between the two densities of two degraded borders. The border at the edge of the denser patch is even denser and the border at the edge of the lighter region is less dense than the average for that region (Mackie Line). The phenomenon, observed by R. Colson (1898) in studying the development by a thin film of solution, has been studied by G. Eberhard (1912) in so far as it concerns the application of photography to scientific purposes. It is generally known as the *Eberhard Effect* or the *edge* or *neighbourhood effect*. When two small light patches on a dark ground (or two dark patches on a light ground) are very close together the concentration of developer exhaustion products is a minimum (or a maximum) between them. This produces a lack of symmetry of their edges that causes an apparent shift in the distance between their centres. This *Kostinsky Effect* is particularly troublesome in making measurements on neighbouring spectral lines, or on double stars, and in motion picture sound tracks.

398. Infectious Development. Usually, the neighbourhood effect manifests itself as a retarding of development of low densities that are contiguous with high densities. However, a case is known in which the partially used developer is more active than the fresh developer and development is accelerated in regions of low density that border on regions of high density.

This phenomenon, called *infectious development* (J. A. C. Yule, 1945) has been found in the case of fine-grain, high-contrast emulsions of the type used for photomechanical reproduction when development is carried out using a hydroquinone developer having a low (0.1 per cent) concentration of sulphite. Thus the gamma is considerably increased without appreciably increasing the fog. This effect was studied by

ingenious experiments involving the mixing and superposition of emulsions of differing colour sensitivity. The catalytic agent that induces the acceleration of development by the hydroquinone was thought to be the semiquinone radical whose prolonged existence is impossible in the presence of the normal concentration of sulphite (§ 409). The application of such a developer to a pen-drawing blocks up the image of fine lines by inducing development of those grains which received by irradiation (§ 212) an exposure that would be too small to cause development under other conditions. The oxidation products that cause development react rapidly with the sulphite of the fresh developer into which they diffuse and the effect of the infection is only manifested over a distance of about 0.1 mm.

A rather similar effect known as *contagious development* was observed on emulsions of the same type as those above when developed in a developer made strongly alkaline with sodium hydroxide and containing traces of hydrazine (e.g. 0.03 to 0.05 g of hydrazine hydrochloride per litre to the first of the developers in § 471 below). The inertia speed and the gamma are approximately trebled without an appreciable increase in fog (R. E. Stauffer, W. F. Smith, and A. P. H. Trivelli, 1944). This effect has been attributed to the fogging of unexposed grains by an unstable compound of hydrazine and a quinonoid oxidation product of the developer formed in the development of exposed grains in the immediate vicinity. The granularity of the image does not allow practical use to be made of this method of intensifying the image by local fogging during development.

The term *infectious development* is used when development spreads to feebly exposed grains, while *contagious development* refers to development spreading to unexposed grains.

399. The Effect of Agitation. The agitation of the bath does not only serve to reduce local irregularities in development such as those mentioned above. When it is sufficient to renew rapidly the developer in contact with the emulsion, and thus to accelerate the diffusion of waste products from the layer, it speeds up development.

In the case of developers that are very susceptible to the influence of bromide, agitation reduces the loss in emulsion speed. In a hydroquinone developer without bromide, the absence of all agitation causes the same regression of the inertia speed that is found in the same developer

when containing bromide and when agitated, the regression being the less as the developer is more violently agitated (S. E. Sheppard and F. A. Elliot, 1923). Some analogous, though less well marked, effects have been found in the case of the other developing agents. In other experiments the same authors (1924) found that the speed of development remained almost constant until the velocity of the solution in contact with the emulsion reached 0.8 metres per second. It reached a maximum when the velocity reached 2.5 metres per second and then decreased until at 10 metres per second, especially in the commencement of development, it reached a value scarcely greater than that found in the static bath.

The agitation must be more efficient as the time of development is decreased, as in developing to a low gamma in a developer of normal concentration, or in developing to a high gamma value in a concentrated developer. The local irregularities in an image developed to a low gamma are exaggerated in the print which is usually developed to a high gamma (§ 605).

One cannot consider as efficacious the agitation produced by rocking a dish, nor the simple motion of film through the solution in continuous processing machines. In the first case the velocity of the solution relative to the emulsion is insufficient, and in the second case the moving film carries with it a sheath of developer that moves at almost the same speed as the film.

In all cases where the time of development is chosen after previously developing a sensitometric strip in the same developer, the degree of agitation must be taken into account, and, if possible, the test strip should receive the same degree of agitation as it is proposed to use with the material to be developed. For example, the time of development of a particular film, in D76 developer, to $\gamma = 1.0$ varied from 9 to 18 minutes (at 18°C) according to the degree of agitation. It should be noted that since the growth of fog depends upon the time of development and not upon the agitation, a film developed to a given gamma is less fogged when the developer is vigorously agitated.

Various methods for obtaining uniform development are described in § 436.

400. The Influence of Temperature. In all developers the rate of development becomes greater as the temperature is raised, but the effect of an increase in temperature varies considerably from one developer to another. On the one hand, all reactions are accelerated by an increase in temperature, and on the other hand

the diffusion of ions into and out of the emulsion is greater at higher temperatures, although this latter effect is somewhat offset by the increased swelling of the gelatine.

Besides accelerating development, a rise in the temperature of the developer sometimes causes an increase in the emulsion speed and always causes an increase in the fog density, the development being carried to the same gamma value for comparison in all cases.

It has been found that, in the case of a metal developer, the emulsion speed of the experimental material increased by about 30 per cent on raising the temperature of the solution from 15° to 25°C (K. Chibisoff and V. Cheltozoff, 1929). It should be noted, however, that in many cases claims of a marked increase of emulsion speed on warming the developer have been discounted when a careful sensitometric examination has been made, the authors having mistaken an increase in the general density of the image for an increase in speed.

The increase in fog density that occurs when the temperature of the developer considerably exceeds 20°C (as, for example, in tropical conditions, or on warming the bath to accelerate development) necessitates the use of an increased concentration of bromide.

If, in the case of a given developer and sensitive material, the times of development that are required to reach a given gamma at two different temperatures are known, the times of development for the same gamma can easily be calculated for other temperatures, because the logarithm of the time of development is proportional to the temperature (W. B. Ferguson, 1906). For example if the same gamma was obtained by 4.9 minutes' development at 10°C and 3.5 minutes at 18°C, the coefficient of proportionality K is given by—

$$K = \frac{\log t - \log t'}{T' - T} = \frac{\log 4.9 - \log 3.5}{8} \\ = \frac{0.6903 - 0.544}{8} = 0.0182$$

where t, t' represent the times of development and T, T' indicate the temperatures.

The *temperature coefficient*, C , of a developer, for a given emulsion relating to the times of development necessary to reach a given gamma at two temperatures differing by 10°C, is given by—

$$\log C = 10 K$$

In the above example $\log C = 0.182$, and $C = 1.52$.

These calculations may be avoided by using the abacus, shown in Fig. 28.7 after W. Heydecker, 1925. To use the abacus, measure on the time scale the *distance* (e.g. with a pair of dividers) between the times of development that were needed to reach the desired gamma value at the two temperatures. Then, starting from the point of the temperature scale corresponding to the difference between the two temperatures under consideration, erect a perpendicular line equal to the measured length. Draw a straight line from the zero of the temperature scale through the end of this perpendicular line and continue it to cut the temperature coefficient scale, on which it will indicate the required value.

In order to find how much the time of development needs to be increased on lowering the temperature of the developer in the above example from 18° to 15°C, draw a straight, oblique line from the zero on the abacus to 1.52 on the temperature coefficient scale. Then measure the *distance* from the 3° mark on the temperature difference scale to this oblique line. Then, starting from the 3.5 minute mark on the time scale measure off (towards higher times) the distance found on the abacus and this will terminate at the required time, in the present example, 4.0 minutes.

Since the time of appearance of the image varies proportionally with the total time of development, the Watkins Factor (§ 381) retains its value unchanged.

The temperature coefficient of a developer varies slightly from one emulsion to another. It does not vary much on changing the concentration of the developer, nor does it vary very much for various developer solutions compounded from the same developing agent. The following table shows most usually found values for the various developing agents.

Developing Agent	C
Metol	1.25
Paraminophenol	1.5
Ferrous oxalate	1.7
Pyrogallol	1.9
Metol-hydroquinone	1.9
Hydroquinone	2.2 to 2.8
Catechol	2.8

In a developer containing two developing agents of different character, the notion of temperature coefficient loses all significance as soon

as the temperature departs far from the optimum. For example, in a metol-hydroquinone developer, the metol alone has any considerable activity at temperatures of about 10°C, while hydroquinone is the more active at temperatures about 20°C. In order to obtain consistent results, it is necessary to maintain the temperature constant. Failing this, the temperature should be measured and account must be taken of its influence on the time of development.

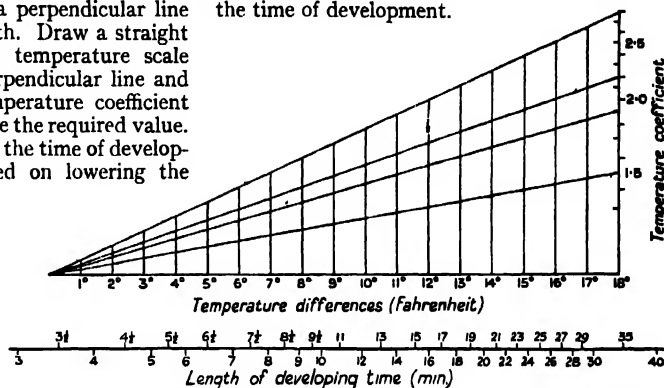


FIG 28.7. GRAPH FOR THE CALCULATION OF EQUIVALENT DEVELOPMENT TIMES FOR DIFFERENT TEMPERATURES

401. Mineral Salts as Developers. In addition to ferrous oxalate (which is the only one of these various developers which has come into effective practical use) and various other ferrous salts (fluoride, citrate, etc.), the following have been suggested for use as developers: cupro-oxalate of ammonia (Carey Lea, 1879); titanoxalates and alkaline molybdo-oxalates (T. Pavolini, 1933); hydrosulphite in alkaline solution (W. B. Bolton, 1893); alkaline peroxides (Le Roy, 1894); or hydrogen peroxide (M. Andresen, 1889) in alkaline solutions.

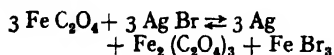
To this class of developers may be added two substances on the border-line between inorganic and organic compounds, namely, hydroxylamine (C. Egli and A. Spiller, 1884), and hydrazine (M. Andresen, 1892), both in alkaline solutions. These substances have never been used in practice as developers, but on various occasions the use of certain of their organic derivatives has been suggested (Lumière and Seyewetz, 1894; W. H. Caldwell, 1908).

402. Ferrous Oxalate Developer. The ferrous oxalate developer, of which the present method of preparation was indicated by J. M. Eder (1879), is now scarcely ever used by either

amateur or professional photographers. Its very low reduction potential does not enable it to develop satisfactorily any but well exposed negatives. Its preparation and use demand more care than is required for organic developers, and afford no material economic compensation for these practical drawbacks. But for various scientific uses of photography this developer possesses the distinct advantage of containing no solvent of silver bromide, and of thus avoiding various disturbing factors which sometimes occur in the use of ordinary developers, but noticeable only in exact localization of points, and in photometric measurements of a high order of accuracy. This developer is the only one with which chemical fog is completely avoided (Hurter and Driffeld, 1890) and which produces a perfectly neutral grey image, completely free from all coloured oxidation products.

The ferrous oxalate developer is prepared *at the time of use* by pouring slowly, with constant stirring, 1 volume of a 25 per cent solution of ferrous sulphate into 3 volumes of a 25 per cent solution of neutral potassium oxalate ($K_2C_2O_4 \cdot H_2O$). This produces a limpid reddish mixture (potassium ferro-oxalate), which can be used as a developer without any addition of potassium bromide.

The reduction potential ($E_{Ag} - E_{Red}$) of the ferro-oxalate developer, which acts according to the equation—



is 44 mv when fresh (W. Reinders, 1935. See § 373).

Over-exposure can be corrected to a certain extent by adding potassium bromide. Being a developer with a low reduction potential, the iron developer is very susceptible to the action of bromides. For correction of over-exposure it suffices to add a relatively small quantity of potassium bromide to the developing bath (e.g. not more than 1 g per litre of bath).

Sodium thiosulphate (hypo) in very minute quantities (a few drops of a 1 : 1,000 solution) has a marked accelerating effect on the ferrous oxalate developer (it decomposes the ferric salts formed), the image then appearing much more rapidly. An excess of hypo produces heavy fog, and, finally, reversal of the image, the fog being then denser than the image proper.

On the negative impregnated with the oxalate solution being placed in the wash-water or the fixing bath, a uniform precipitation of calcium oxalate takes place in the upper layers of the

gelatine, forming a white deposit. During washing, after fixing, this deposit is readily removed by placing the negative for a few moments in a very weak solution of hydrochloric acid, e.g. 1 : 200 solution (= about 5 ml in 1 litre).

403. Sodium Hydrosulphite Developer. The use of sodium hydrosulphite as a developer was proposed by W. B. Bolton (1893). Sodium hydrosulphite, more systematically known as sodium dithionite, is a white powder which when pure has the molecular formula $Na_2S_2O_4 \cdot 2H_2O$. Its neutral solution can be used to develop positive emulsions, but it needs to be acidified by sodium bisulphite, or by an acid, organic buffer, in order for it to be able to develop negative emulsions. On being exposed to air, a solution of sodium hydrosulphite loses its developing power without losing its reducing properties. The partly oxidized solution produces warm-toned images on chloride papers.

A "developer-desensitizer" for non-colour-sensitized emulsions was suggested by A. Seyewetz (1931). To prepare it, dissolve immediately before use 12 g of an intimate mixture of—

Sodium hydrosulphite	100 g
Potassium bromide	35 g
Sodium bisulphite	105 g

The appearance of the image is much delayed, but once it has appeared the gamma increases rapidly. The emulsion speed of a material developed in this way to $\gamma = 2.6$ is less than 10 per cent of that obtained by developing the same material to $\gamma = 1.0$ in a metol-hydroquinone developer. The energy of the developer can be somewhat increased by the cautious addition of acid, but this procedure involves the risk of causing fog. The dry, powdered mixture will keep well in a tightly stoppered bottle, but the solution is unstable, evolving a sulphurous gas which makes its use very unpleasant in a confined space.

After one minute's immersion in the developer, the speed of the emulsion is reduced to about 5 per cent of normal and a very bright safelight can be used.

If colour-sensitized materials are developed in this solution an intense fogging results. In order to develop transparencies, or paper prints, the concentration of the solution should be reduced. After 30 seconds' immersion a bright yellow safelight may be used.

ORGANIC DEVELOPERS

404. The Developing Function. It has already been mentioned (§ 373) that any solution whose

reduction potential falls within certain limits can be used to develop a latent image. But a large number of the substances that would qualify in this way as developing agents are eliminated by practical considerations. For a reducing agent to be a successful developing agent it must be able to develop images of very low exposures, without much tendency to fog. It must be sufficiently soluble in water and the solution must be stable and non-toxic. Its cost per unit area of film developed must not be excessive. Except in a few specialized applications, the developing agent should give a neutral grey image.

The earliest organic developing agents known were derivatives of benzene, and naphthalene, and their homologues (aromatic compounds). In 1891 M. Andresen, and A. and L. Lumière independently formulated a rule by which it was possible to predict if a substance, of known chemical structure, would act as a developing agent. Although a number of exceptions are now known to this rule, which has, moreover, often needed revision, it applies to almost all the developing agents in current use. The essential clause of this rule is as follows.

In order that an aromatic compound should be a developing agent, two carbon atoms in the nucleus (the same nucleus in multi-ringed com-

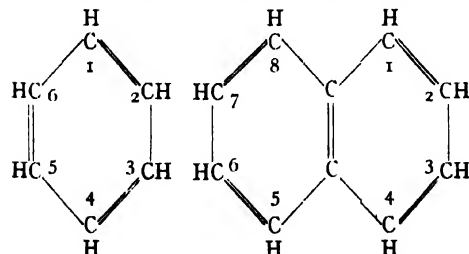


FIG. 28.8. STRUCTURAL FORMULA FOR BENZENE

FIG. 28.9. STRUCTURAL FORMULA FOR NAPHTHALENE

pounds) in *ortho* or *para* positions must each carry a hydroxyl ($-\text{OH}$) group or an amino ($-\text{NH}_2$) group. The *ortho* position signifies that the $-\text{OH}$ or $-\text{NH}_2$ groups would be substituted for the hydrogen atoms in positions 1 and 2 in the benzene and naphthalene molecules whose structure is indicated above in Figs. 28.8 and 28.9. The *para* position, in the same way, would be represented by positions 1 and 4 in the two structural diagrams. A substance possessing a structure such that it satisfies this

rule is said to possess the *developing function*. Thus, of the three dihydroxy derivatives of benzene, all of the same formula $\text{C}_6\text{H}_4(\text{OH})_2$, the *ortho* derivative, catechol, and the *para* derivative, hydroquinone, are developing agents. The other, or *meta* derivative, resorcinol will not normally develop, although it is a reducing agent.

The presence of further hydroxyl or amino

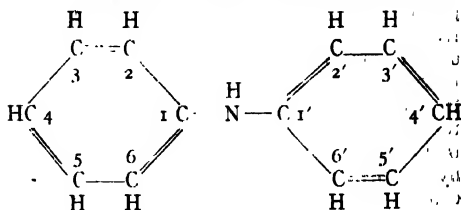


FIG. 28.10. STRUCTURAL FORMULA FOR DIPHENYLAMINE

groups in the same nucleus in a position *ortho* or *para* to one of the two essential groups increases the developing power.

The hydrogen atoms of the amino ($-\text{NH}_2$) group or groups may be partly, or all, replaced by hydrocarbon or alcoholic groups without losing the developing function. For example, as an extreme case, the replacement of the 4, 4' hydrogen atoms in diphenylamine (Fig. 28.10) by $-\text{OH}$ or $-\text{NH}_2$ yields developers which can be considered as resulting from the substitution of $\text{C}_6\text{H}_4\text{OH}$ or $-\text{C}_6\text{H}_4\text{NH}$ in the $-\text{NH}_2$ group of paraminophenol or of paraphenylenediamine. No substitution is possible, however, in the case of the hydrogen atom in the $-\text{OH}$ group.

The developing properties can be modified, or removed, by the presence of other substituents in the nucleus. Chlorhydroquinone $\text{C}_6\text{H}_2\text{Cl}(\text{OH})_2$, paramino-*ortho*-cresol $\text{H}_2\text{N} \cdot \text{C}_6\text{H}_3(\text{CH}_3)_2 \cdot \text{OH}$, are more active than the hydroquinone and paraminophenol from which they are derived. Again, the introduction of a sulphonic acid group ($-\text{SO}_3\text{H}$) transforms an insoluble substance such as aminonaphthol into a water-soluble substance such as eikonogen (1-amino-2-naphthol-6-sodium sulphonate).

Among the developers not provided for by these rules, and of which a number have been recently patented for use in fine-grain and colour developers, are various derivatives of N-heterocyclic compounds related to pyridine and quinoline such as 2, 5, diaminopyridine and 2-hydroxy-5-aminopyridine (A. E. Tschitschabin, 1944), oxytetrahydroquinoline (Lembach

and Scheicher, 1895), and aminotetrahydroquinolines (W. D. Peterson, 1938); also various derivatives of pyrimidines (G. Willmanns, H. Fricke, and E. I. Berr, 1935).

405. Normal Constituents of a Developer. Although it is possible to obtain faint traces of an image (L. P. Clerc, 1909; E. Cousin, 1912) by treating a sensitive film in a very dilute pure aqueous solution of some developers (diaminophenol, paraphenylene-diamine, and its derivatives, etc.), it is usually necessary, in order to obtain a vigorous image in a reasonable time, to render the developing solution alkaline, so that the hydrobromic acid resulting from the reduction of the silver bromide may be neutralized as it is formed. A pure aqueous solution of hydroquinone does not develop, but a solution containing 5 per cent of hydroquinone and 5 per cent of caustic soda develops a satisfactory image in about three minutes, without fog or appreciable stain (C. E. K. Mees and C. W. Piper, 1911). The caustic alkali may, moreover, be replaced by the salt of a weak acid, easily displaced by the hydrobromic acid and not itself preventing development, provided that the solution has a pH that is sufficiently high for the developing agent under consideration. This is the case with the carbonates and various other salts, among which are the sulphites. With the latter, development is exceedingly slow, except with the developers capable of developing an image in an aqueous solution (about one hour is required to develop a complete image in a very concentrated sulphite solution of pyro). Development is completed in a normal time by adding a carbonate (of sodium or of potassium) to the pure aqueous solution of a developer substance, but these solutions (like nearly all others compounded with a caustic alkali) oxidize in the air with very great rapidity, thus giving rise, during the time necessary for development, to brown oxidation products, which strongly stain the gelatine.

In 1882 H. B. Berkeley observed that the addition of a sulphite to the alkaline solution of a developer considerably delays this oxidation and opposes the formation of the highly-coloured products obtained in the absence of this *preservative*. While sulphite must be considered a necessary constituent of all developing solutions compounded with organic developers, it is not entirely advantageous. While it increases the energy of a solution of paraminophenol and carbonate (M. Andresen, 1898), it retards development with a solution of hydroquinone

and carbonate (J. Desalme, 1921), and furthermore, as a solvent of silver bromide (with which it forms a soluble double sulphite) it favours the formation of fog.

Other substances have been suggested for use instead of sulphite to protect the developing agents from being oxidized by atmospheric oxygen. Greater protection is afforded by substances containing an $-SH$ (thiol) group, such as cysteine and thioglycolic acid (T. H. James and A. Weissberger, 1939). The protection appears to be due, as with sulphite, to the destruction of quinonoid oxidation products which catalyse the oxidation of hydroquinone.

Finally, in many cases a bromide, added in small quantities to the developing bath, must be used as a *restrainer* of chemical fog (§ 386 to § 388).

406. The Role of the Alkalis in Development. Besides neutralizing the hydrobromic acid which is liberated in development (in the case of silver bromide), the alkali must liberate the free base of those developing agents that are usually supplied in the form of a salt for greater stability in storage, e.g. metol. The alkali facilitates the dissociation of acidic hydroxyl ($-OH$) groups by forming phenolates. Finally, the pH of the developer is one of the factors that influences the reduction potential, which increases with the alkalinity of the developer solution (§ 374).

If the activity of a developing agent is the same in various fresh developer solutions at the same pH , these solutions may behave very differently after some use, or after storing in contact with air. In both cases the pH of the developer solution would have changed, and not necessarily in the same direction. As will be described below, the pH of hydroquinone-sulphite solutions increases on aerial oxidation, while oxidation by a silver halide decreases the pH . The extent of the change in pH depends upon the buffering capacity of the other constituents of the developer (§ 295). A mixture of sulphite and carbonate gives quite good buffering at pH 10, while salts such as borate and phosphate are very useful buffers at pH levels about 9.4 and 10.5 respectively and may be used with advantage in developers at about these pH values. However, borates should be avoided when using developing agents, such as catechol and pyrogallol, containing hydroxyl groups in *ortho* positions because of the formation of complexes.

The behaviour of three buffers is shown by

the full curves in Fig. 28.11 (W. Reinders and M. C. F. Beukers, 1931). Three developers were prepared, each containing 11 grammes of hydroquinone and 38 grammes of sulphite, per litre. The first was buffered with 10.05 grammes of borax (B), the second with 8.4 grammes of sodium bicarbonate (C), and the third with 35.8 grammes of disodium hydrogen phosphate (P). The course of the change in pH is shown as sodium hydroxide was added. The vertical

atmospheric oxygen is greater as the alkalinity of the solution is increased. For this reason the pH of the developer should not be increased beyond the minimum value necessary. Besides, high alkalinity promotes a detrimental swelling of the gelatine.

407. Ammonium hydroxide and ammonium carbonate can serve as alkalis in developers, but their use is limited to certain special cases. By virtue of their solvent power for silver

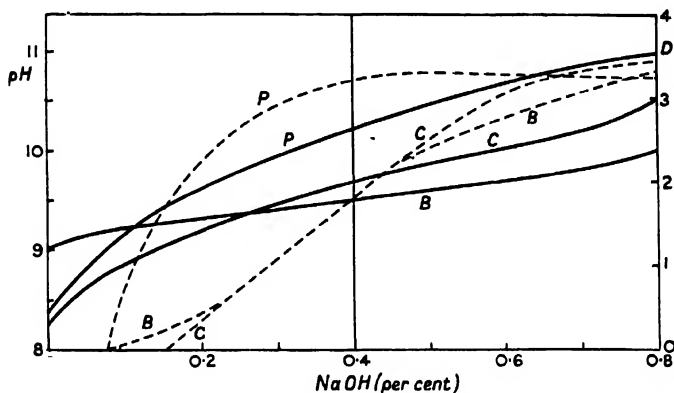


FIG. 28.11. BUFFERING EFFECT OF BORAX, SODIUM BICARBONATE AND DISODIUM PHOSPHATE

line at 0.4 per cent NaOH indicates sufficient sodium hydroxide to make an equivalent amount of metaborate, carbonate, and trisodium phosphate from the respective buffers. The broken curves show the densities obtained in 10 minutes' development (right-hand scale) on plates that had all received the same exposure.

The full curves show that, in the pH range 9 to 10, the borax buffer was the best, the bicarbonate was acceptable, while the phosphate was mediocre.

The optimum value of the pH varies from one developing agent to another. The following table shows the approximate pH range within which some developing agents can be effectively used (W. Reinders and M. C. F. Beukers, 1931).

Developing Agent	pH Range
Metol	6-9.5
Paraminophenol	7.5-12
Pyrogallol	8-9.5
Glycin	8.5-11.5
Hydroquinone	9.5-11
Paraphenylenediamine	10-13

The rate of oxidation of the developer by

chloride and bromide, they favour the formation of *dichroic fog* (§ 385). In a slow-acting developer, ammonium hydroxide limits the values of gamma and maximum density that can be reached. Some of the silver, reduced from the silver halide dissolved from the emulsion, is deposited on the walls of the dish (J. Vidal, 1931). In some cases a derivative of ammonia may be used. Triethanolamine, for example, is more strongly alkaline than ammonium hydroxide and has less solvent action on silver halides.

The addition of acetone or formaldehyde to a sulphite solution results in the formation of an acetone-, or formaldehyde-bisulphite with the consequent liberation of an equivalent amount of sodium hydroxide (Lumière and Seyewetz, 1896). Developers have been used consisting of a solution of sulphite and pyrogallol to which acetone is added. In such developers, if the quantity of sulphite was not in excess of the acetone, the concentration of sulphite is greatly reduced and the image obtained is brown as a result of the formation in the gelatine of a *secondary image* (§ 413) by the oxidation products of the pyrogallol.

Thus, in order to obtain images of high contrast by infectious development (§ 398), hydroquinone developers are made alkaline by the addition of formaldehyde, used in the form of a solution or as the solid polymer, trioxymethylene which depolymerizes when dissolved in a sulphite solution (Lumière and Seyewetz, 1902).

408. Role of Sulphite. The quantity of sulphite to be used in a developing solution depends on the nature of the developer and of the substances used to render it alkaline, on the dilution of the bath, on the degree of keeping quality desired in partly emptied bottles or in developing tanks, and on the prevailing temperature.

For instance, very little sulphite is required with glycine (the spontaneous oxidation of which is negligible) and with paraphenylenediamine (the oxidation products of which are then almost colourless), while a relatively large quantity is required with pyro solutions to avoid staining the image.

Developing solutions made alkaline with caustic alkalis tend to oxidize more rapidly than those containing carbonates; for this reason the sulphite content should be somewhat increased with the former. All other conditions being equal, the proportion of sulphite to developer must be greater in a dilute solution than in a concentrated one.

With most developers, if the developing solution is prepared shortly before use and is used once only, a sulphite content of about 1 per cent of the anhydrous salt is sufficient. It is, moreover, at this strength that the solubility of silver bromide in solutions of sulphite reaches its minimum; thus chemical fog is markedly reduced (Mees and Piper, 1912). The amount of sulphite must be increased when a developing solution has to be kept long in a partly empty container, especially when there is a large surface in contact with air (solution left in a developing tank without a floating cover) and in all cases where air has free access to the emulsion during its development (development of film on continuous machines or drums, and development in tanks where the developer is kept in motion by a stream of air).

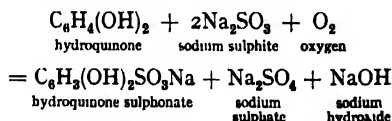
Finally, as an appreciable rise in temperature always accelerates the atmospheric oxidation of the developing solution, it is necessary in hot climates to counteract this effect by increasing the quantity of sulphite specified for use in temperate countries.

The fact that a small quantity of the silver

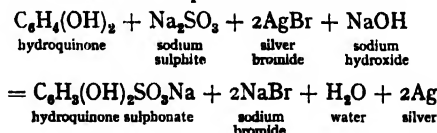
halide dissolves in the sodium sulphite used as a preservative of the developing solution against oxidation results in the solution behaving, to a certain extent, like a physical developer; the dissolved silver salt is reduced by the developer and deposits itself, partly in the liquid and on the walls of the tanks, and partly on the image itself, which is thereby reinforced.

409. The mechanism of the mutual protection that sulphite and certain developing agents afford to each other against aerial oxidation (autoxidation) has not yet been worked out, but it has been studied in the case of polyphenols and especially in the case of hydroquinone.

Whereas the oxidation of hydroquinone in an acid or feebly alkaline solution yields quinone, this product is not found as a result of oxidation in the presence of an excess of sulphite. Quinone is instantaneously transformed into hydroquinone monosulphonate when added to an alkaline sulphite solution. It is this substance which constitutes the first end-product of the oxidation of hydroquinone in the presence of sulphite (J. Pinnow, 1913). In the case of autoxidation the reaction proceeds—



In the case of development the reaction is—



It will be seen that, whereas in the second case some of the available alkali is neutralized, in the first case sodium hydroxide is formed by the autoxidation. This explains the observation (Lüppo-Cramer, 1931) that a sulphite solution of hydroquinone that does not develop when freshly compounded, becomes quite active after storing it for several days in a partly filled bottle. It should be noted, moreover, that when the constituents of a developer are put up in two solutions to be mixed just before use (the developing agent in one and the alkali in the other), the oxidation of the developing agent is not avoided merely by adding sulphite to that part. It is necessary to acidify the solution, for example, by adding bisulphite.

The hydroquinone monosulphonate that is formed by the oxidation of hydroquinone is itself a feeble developer, and if the oxidation of the solution is continued, by development or by exposure to air, hydroquinonedisulphonate is formed, whose presence in solution is marked by an intense blue fluorescence.

The protective action of sulphite is the result of its preventing the formation of quinone or quinonoid products which, in the absence of sulphite, energetically catalyse the autoxidation of hydroquinone (T. H. James and A. Weissberger, 1939).

410. The Formation of Sulphide in Used Developers. Used developers that are kept for long periods away from air, as in stoppered bottles and deep tanks, may, when used, give a fog due to the formation of sulphide as a result of bacterial decomposition of the sulphite (M. L. Dundon and J. I. Crabtree). This occurrence is encountered mostly in summer, the optimum temperature for the growth of the anaerobic bacteria, whose presence is made possible by the gelatine dissolved from the developed emulsions, lying between 25° and 40°C.

When the concentration of sulphide is very small, the bath is cleared by the first few films or plates that are developed, and no fog appears on those developed immediately afterwards. However, the fog reappears on recommencing development after a suspension of work. When the concentration of sulphide is appreciable the bath gives off the odour of rotten eggs especially when stirred. In such a case the bath can only be used after adding lead acetate, agitating, and allowing the insoluble lead salts (sulphide, etc.) to settle or filtering them off. When the system becomes infected in this way it is necessary to disinfect the whole system, tanks, baths, pumps, and pipes. Strong disinfectants such as sodium hypochlorite, permanganate, or pentachlorophenate (Santobrite) may be used, the choice depending upon the materials of which the system is constructed.

Disinfectants that can be added to the developer without adverse effect include—alkaline fluorides and fluosilicates, sodium salicylate (2 g per litre), parachlormetacresol (1 g per litre), Sunoxol (ortho-oxyquinoline sulphate, 0.1 g per litre), and various derivatives of acridine yellow.

411. Complex Developers. By using a mixture, in suitable proportion, of two developing agents of different characteristics, one of a low and another of a high reduction potential, it is often possible to obtain results superior to

those obtained by using either agent separately. The best combination is that of metol and hydroquinone. The density obtained in a given time of development in this developer is greater than the sum of the densities that would be obtained on similar exposures developed separately in a metol, and a hydroquinone developer, each developer containing only one of the developing agents in the same concentration as it was used in the combined developer (Lüppo-Cramer, 1902). In such a complex developer the image appears rapidly (metol characteristic) and its density grows rapidly (hydroquinone characteristic). Finally, the yellow fog that is often found on images developed in hydroquinone is avoided.

Similar, though less valuable, results are obtained when metol is used in association with pyrogallol or with glycin, and when a small concentration of amidol is used with hydroquinone (Lüppo-Cramer, 1921).

The same results are obtained when the sensitive material is first bathed in a solution of amidol (H. Frötschner, 1937) or in a solution of metol (T. H. James, 1940) followed, immediately afterwards, by development in a hydroquinone developer. The same acceleration of development is obtained by adding safranin to a hydroquinone developer or by immersion in a very dilute solution of safranin before developing in a hydroquinone developer (R. Namias, 1921).

It would seem that the behaviour of these "super-additive" or "non-additive" complex developers is due, in part at least, to the greater ease with which an aminophenolic developing agent, having a single negative electrical charge, can cross the negative charge barriers that are situated in the gelatine and, by virtue of adsorbed bromide ions, on the surface of the silver halide grains (§§ 377 and 379). Thus the metol, by shortening the induction period, causes the development of a greater number of grains (which is equivalent to an increase in the emulsion speed) before the contrast becomes excessive (T. H. James, 1943).

412. Many addition compounds formed from a polyphenolic developing agent and the *free base* of an aminophenolic or a diamino developing agent have been commercially available to facilitate the ready preparation of developing solutions by amateurs, who need only dissolve the compound in a sulphite solution. The addition of alkali is not necessary in some cases. As soon as the addition compounds are dissolved they dissociate into their constituent parts.

The free base initiates development which is then continued by the polyphenol. Among those compounds that are still available, *metoquinone* (A. and L. Lumière and A. Seyewetz, 1903) containing one molecular equivalent of hydroquinone to two of metol base, and *Meritol* (1936) containing an equimolecular combination of catechol and paraphenylenediamine, may be noted. Other combinations, no longer available, are *Oriol* (J. Hauff, 1897) containing hydroquinone and orthoaminophenol, *Hydramine* (Lumière and Seyewetz, 1899) consisting of hydroquinone and paraphenylenediamine, and *Chloranol* (Lumière and Seyewetz, 1913) containing chlorhydroquinone and metol base.

413. Oxidation Products of Developers ; Tanning ; Secondary Images. The quinonoid oxidation products of developers that are formed in the absence of sulphite, or in the presence of a very low concentration of sulphite, are deposited in the gelatine at the site of development, and in a quantity proportional to the amount of silver halide reduced. Usually they polymerize, giving rise to coloured, tanning substances of the nature of the humic acids, whose exact constitution is unknown.

After removing the silver image by bleaching with a weak oxidizing solution, such as ferricyanide-thiosulphate (Farmer's Reducer), a yellow or brown *secondary image* remains, which, though it may not appear very intense to the eye, can give acceptable prints on high contrast paper, because of its absorption of actinic light. The following table (Lumière and Seyewetz, 1928) shows the colour of the secondary image obtained in various developers, its relative intensity and the concentration of sulphite necessary to prevent its formation.

Developer	Colour	Relative Intensity	Sulphite (grammes per litre)
Pyrogallol	Yellow-orange	10	11
Catechol	Black	10	6
Hydroquinone	Yellow-brown	10	2
Chlorhydroquinone	Yellow-brown	10	2
Amidol	Reddish-brown	8	2
Paraminophenol	Brownish-black	3	2
Metol	Brownish-black	2	1
Paraphenylenediamine	Grey	1	—
Glycin	None	0	—

The secondary image is destroyed or weakened by acid stop baths and acid fixers.

Of the usual developing agents, pyrogallol and catechol give the most effective tanning.

414. The *tanning developers* are sometimes

inconvenient, but, on the other hand, they lend themselves to interesting practical applications.

To quote the disadvantages first, the tanning of the gelatine that takes place during development in proportion to density of the image already formed, slows down the process of diffusion of fresh and exhausted developer, particularly in the high densities, thus depressing that part of the characteristic curve which would otherwise be the straight line portion (K. Jacobsohn, 1928). Again the differential tanning between contiguous areas of different density causes, on drying, local deformation of the image (F. E. Ross, 1921) that is especially harmful when the image is to be used for exact measurements.

Among the applications of differential tanning to be noted are relief images, particularly for collotype matrices, on thin films exposed through the support, the unhardened gelatine being washed away in warm water after development ; also for transferring to metal, resists are copied on paper, coated with an emulsion which is dyed to limit the penetration of the light (§ 390), the paper being stripped in warm water after the image has adhered to the support.

415. The formation of stain images by the oxidation products of the developing agent in a developer having a zero or a low concentration of sulphite, has found practical application. A process of intensification, based on the formation of stain, will be described later (§ 553).

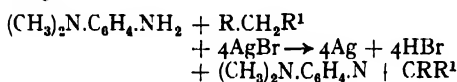
The secondary image acts as a mordant, fixing basic dyes (A. and L. Lumière and A. Seyewetz, 1928), thus giving rise to the possibility of intensifying the image by immersion in a suitable solution of such dyes (§ 754).

The stain image possesses marked reducing properties towards various metallic salts or complexes (F. Leiber, 1932). It may be intensified by immersion in the copper ferrocyanide toner (§ 749), or in an ammoniacal solution of silver nitrate. This last reaction has served as the basis for a reversal process (§ 529). The humic acids of the stain image that are formed from polyphenolic developing agents can still, by virtue of their phenolic nature, couple with diazonium compounds (§ 839) to give azo dyes (R. Jodl, 1938).

Some developing agents, of no practical interest, give vividly coloured, insoluble oxidation products. In this way, after removing the silver, one can obtain a blue image after developing by indoxyl, or red after developing with thioindoxyl (B. Homolka, 1906).

416. Colour Development. Intensely coloured

images are obtained using aminophenols or diamines (with one unsubstituted amino group) as developing agents when the developer contains a *coupler* which participates in the reduction of the silver halide. The oxidation products of the developing agent and the coupler yield an insoluble and non-wandering dye at the site of reduction of the silver halide grains, the quantity of dye formed being proportional to the amount of silver reduced (R. Fischer, 1912). Since the coupling reaction increases the reduction potential, developing agents can be used which, in the absence of the coupler would need to be used at a pH level higher than the gelatine would tolerate (A. G. Tull, 1939). For example, a developer containing dimethylparaphenylenediamine gives, in the presence of a substance such as an aceto-acetic ester or dibenzoylmethane a yellow or red dye image duplicating the silver image.



(where R, R¹ indicate negative radicals, such as CO or CN, so that the H atoms of the CH₂ group are labile).

Under the same conditions, an aminophenol yields an indophenol in the presence of a phenol, whereas a diamine gives an indo-aniline or an oxazine in the presence of a phenol, and an indamine in the presence of an amine.

Because they react with the coupler, the concentration of the oxidation products of the developing agent is always very low. In this sense the coupler behaves in the same way as sulphite. The presence of sulphite is often necessary and the ratio between the quantity of dye formed and the quantity of silver reduced varies to a large extent with the sulphite concentration (R. M. Evans and W. T. Hanson, 1937).

When the silver image and the residual silver bromide are removed (simultaneously by Farmer's reducer) the granularity of the image is very low.

For an experimental test, a deep blue image can be obtained in a developer containing asymmetric dimethylparaphenylenediamine, potassium carbonate, and about 1 per cent 1:4 naphtholsulphonic acid, prepared immediately before use. Fix in a plain hypo solution because the blue colour is destroyed in an acid bath.

The colour developers usually require an increase in exposure. Some of them tend to

give fog, though this can sometimes be avoided by applying the colour development to an image that has been developed, fixed, washed, and rehalogenated, usually to the chloride.

An attempt made in 1914 to launch positive papers containing a coupler in the emulsion met with no success, the colours obtained being too fugitive. The process was taken up again (L. D. Mannes and L. Godowski, 1935) in working out a process of natural colour photography (§ 1012).

The use of dye development for the production of black-and-white prints has been suggested (J. Kleine and G. Willmanns, 1936) so that all the silver could be recovered.

Sometimes undesirable reactions take place between the colour developer and the dyes in certain antihalation layers.

417. The Effect of Various Substances added to Developers. Iodides. The addition of iodide at a concentration (0.02 to 0.2 per cent) much lower than that needed to bring about depth development, considerably reduces the induction period of developing agents having a low reduction potential. In the case of hydroquinone the Watkins Factor is quadrupled. This acceleration of the early stages of development was noted by A. Lainer (1891) and is often called the *Lainer Effect*. A close study of this effect (S. E. Sheppard and G. Meyer, 1920) showed that, on adding iodide, silver bromide precipitated in the absence of gelatine adsorbed a greater quantity of safranin. It is thus possible that iodizing favours the adsorption of the oxidation products of the developing agents, in this way accelerating the start of development.

Thiocarbamide (thiourea). The addition, to a hydroquinone developer, of a small concentration (about 0.04 per cent) of thiocarbamide (§ 502) causes a dense positive image of a somewhat violet hue to form after the neutral-grey negative image has started to appear (J. Waterhouse, 1890). This effect can also be obtained with thiosinamine (allylthiourea) and phenylthiocarbamide. It is most marked in a strongly alkaline developer having a low bromide concentration and used at about 15°C. It does not occur in a strongly bromided developer (A. H. Nietz, 1922), nor in an acid developer. An explanation of the effect was given by S. O. Rawling, 1926. The thiocarbamides are adsorbed by the silver bromide with which they form insoluble complexes which, in an alkaline medium, decompose to form silver sulphide. This decomposition is considerably retarded

by soluble bromide. The development of the negative image commences before the grains are thus infected (similarly when the emulsion is treated with the thiocarbamide before development) and the reversal appears only when the negative image is visible, the positive image being formed as the result of local variations in the bromide concentration in the emulsion. The sulphided grains, which are more numerous where the negative image is less dense, are rapidly developable.

Alcohols. The addition of alcohols has been recommended in the case of developers which are prepared in very concentrated form, in order to avoid the precipitation of the base of aminophenolic developing agents or their addition products with hydroquinone. Sometimes alcohols (from methyl to butyl) are added to developers in order to limit their penetration into the emulsion so as to obtain a surface image.

In the case of developers containing hydroquinone and made alkaline by a carbonate, the addition of ethyl or methyl alcohol in appreciable quantity gives rise to fog.

Neutral Salts. The degree of swelling of gelatine in an aqueous solution is reduced by increasing the salt concentration. If a developer cannot be maintained at a temperature below 25°C, excessive swelling can be avoided by adding a neutral salt having a negligible effect on development (L. J. Brunel, 1910). Of the various salts that may be used (sulphates, nitrates, phosphates, oxalates), sodium sulphate is usually chosen on account of cheapness. Sodium sulphate is sometimes used, also, to limit the penetration of the developer, reducing the depth of the image in the emulsion layer and reducing the gamma.

In a developer having a very low salt concentration, as in the case of amidol developers, the addition of sodium sulphate at a moderate concentration helps to coagulate the colloidal silver that tends to accumulate in the bath, especially when developing fine-grain positive emulsions, thus avoiding the danger of dirtying the whites of the image (L. Lobel, 1920).

The addition of citrates (§ 747) and tartrates, or their acids, to developers causes, in the case of developing agents of low reduction potential, a depression of density and a regression of the speed comparable, in some degree, to the effect of bromide (L. Lobel and J. Lefevre, 1927). This effect seems to be due to a limitation of the dissociation of the carbonate by these salts. A. von Hübl showed, in fact, that the addition of

citrate and tartrate (as well as the addition of glycerine) reduced the electrical conductivity of a developer, and probably also the dissociation of the alkali.

Silver Bromide Solvents. The additions, even in very small concentration, of a silver halide solvent to a hydroquinone developer tends to give dichroic fog (§ 385). In the case of metal developers the addition of a small concentration of a solvent tends to dissolve the surface of the grains, reducing their diameter, and helping to obtain images of low granularity (§ 473). Increasing the sulphite concentration increases the solvent power, though this can be achieved by adding a small quantity of a solvent such as a thiocyanate to a developer containing a normal sulphite concentration.

Various. Development can be slowed down by adding to the developer various substances such as glycerine, sugars, etc., which, by increasing the viscosity of the solution, limit its penetration in the gelatine and slow down the exchanges between the emulsion and the solution in which it is bathed (W. de Abney, 1897; L. Baekeland, 1899). These measures tend to give a superficial image of reduced contrast.

Glucose has been recommended as a stabilizer in concentrated developers containing caustic alkali (E. Fournes and H. Diamant-Eerde, 1935).

Wetting Agents. The wetting of the emulsion layer is facilitated, and the risk of the adherence of air-bells is reduced, by the addition to the developer of about 1 g per litre of one of a number of substances that reduce the interfacial tension between water and solid surfaces: alkaline sulphorcinates, the sulphonates of higher fatty alcohols (known under trade names such as Alkanol, Igepon, Teepol, etc.), saponin, pyridine, etc. The same substances may also be used in a pre-bath. These wetting agents must be used in higher concentration in acid or neutral solutions than in alkaline solutions. It should be remembered that these substances will give rise to foam in developers that are violently agitated.

Wetting agents may be usefully added to all baths and to dyes or pigments for tinting or spotting. Their presence in the last wash-water facilitates flowing during draining and avoids the adherence of drops which may give rise to drying marks.

THE USUAL COMPONENTS OF DEVELOPERS

418. Organic Developing Agents. The more important organic developing agents are discussed in the following paragraphs, classified

according to their chemical nature. The properties of each group are indicated, then the properties of each particular substance. Most of the developing agents are known commercially under a number of synonymous trade names.

419. Polyphenols. The polyphenols are substances of a weakly acid nature which give phenolates with alkalis, the metal replacing the atom of hydrogen in one or more of the hydroxyl ($-\text{OH}$) groups. With alkaline carbonate solutions the formation of phenolates is always very incomplete and most of the polyphenol can be extracted from the solution on shaking it with ether. The *para* phenols show the acid properties to a more marked degree than the *ortho* compounds, but the latter form strongly acid complexes with the salts of boric acid, e.g. borax.

Hydroquinone. Hydroquinone, *paradihydroxybenzene*, quinol, 1 : 4— $\text{C}_6\text{H}_4(\text{OH})_2$, molecular weight 110, was proposed as a developing agent by W. de Abney in 1880. It usually appears as small, colourless, needle-like crystals, melting at 170°C without decomposition. It is odourless when pure. It is very soluble in alcohol (40 per cent), somewhat less so in ether and acetone (15 per cent), and is slightly soluble in water (5.7 per cent at 15°C , more when warmer). It is insoluble in benzene. Hydroquinone gives the diphenolate with caustic alkalis, and principally the monophenolate with alkali carbonates and other alkaline salts. At one time a crystalline substance containing hydroquinone and sulphur dioxide $3 \text{ C}_6\text{H}_4(\text{OH})_2 \cdot \text{SO}_2$ was obtainable under the name *hydroquinone yellow*.

Hydroquinone is stable in dry air. When dissolved in an alkaline solution (without sulphite) in contact with air, the solution rapidly turns yellow and then brown, and gives off the sharp odour of quinone. A peroxide is formed as an oxidation intermediate (T. H. James, I. M. Snell, and A. Weissberger, 1938). At equal pH values, the oxidation of hydroquinone may be 13 times as rapid in a borate buffer than a phosphate buffer (A. St. Maxen, 1935), the latter inhibiting the catalysis of the oxidation by traces of copper salts. It has been mentioned above (§ 409) that, in the presence of sulphite, the autooxidation of hydroquinone yields the monosulphonate, then the disulphonate. Further oxidation yields the same humic acids as are found in oxidation in the absence of sulphite. The oxidation of hydroquinone is considerably accelerated by magnesia (A. St. Maxen, 1932).

Hydroquinone is used, with strong alkalis and

with a high concentration of potassium bromide, for the development of slow, high-contrast emulsions in the copying of documents, eliminating tones intermediate between black and white. Used with carbonates, it gives warm tones on fine-grain positive emulsions.

For the development of continuous-tone negatives, hydroquinone is almost always used together with metol.

Chlorhydroquinone. Chlorhydroquinone, or chlorquinol, $\text{C}_6\text{H}_3\text{Cl}(\text{OH})_2$, molecular weight = 144.5, known also as Adurol or Quinolol, was proposed as a developer by Lüppo-Cramer in 1899. It occurs as almost colourless needles, melting at 106°C . It is more soluble than hydroquinone in water (about 50 per cent at 15°C). Unlike hydroquinone it is soluble in warm benzene. Its reduction potential is higher than that of hydroquinone, and under normal conditions it gives a blacker image.

Catechol. Catechol, pyrocatechin, orthodihydroxybenzene, 1 : 2— $\text{C}_6\text{H}_4(\text{OH})_2$, molecular weight = 110, was introduced as a developer by J. M. Eder and Tôth in 1880. It forms plate-like crystals which are colourless when completely pure but which usually have a pink or greyish tinge. It has a strong coal-tar odour and melts at 105°C . It is very soluble in alcohol, ether, acetone, in water (30 per cent at 15°C), and in warm benzene. A solution containing catechol and borax is strongly acid and will turn litmus red and liberate carbon dioxide from carbonates.

Catechol is used chiefly in the preparation of tanning developers (§ 413) containing a very low sulphite concentration.

Pyrogallol. Pyrogallol, 1 : 2 : 3-trihydroxybenzene, "pyro," $\text{C}_6\text{H}_3(\text{OH})_3$, molecular weight = 126, improperly called pyrogallol acid, was introduced by V. Regnault in 1851. It appears both as a very light, white powder, or as small colourless crystals (sometimes called *Pyral*). It melts at 133°C , and is very soluble in alcohol, ether, acetone, water (almost 40 per cent at 15°C), and is slightly soluble in warm benzene. The aqueous solution rapidly turns brown when exposed to air, the oxidation being accelerated by the addition of alkali. The oxidation products stain the skin and nails brown.

Since pyrogallol solutions are stable only when acid, they are usually prepared by mixing two stock solutions, one containing the pyrogallol with bisulphite, and the other the alkali. The maximum energy is achieved by using a caustic alkali in quantity sufficient to form the

monophenolate (E. Valenta, 1902), i.e. 32 g of sodium hydroxide per 100 g of pyrogallol beyond the quantity required to neutralize the bisulphite. Further addition of alkali gives rise to a dense fog and discoloration of the bath.

While pyrogallol has long been used for the development of plates and films, its poor keeping qualities make it unsuitable for large-scale industrial use. It has been suggested that its monomethyl ether (Rubinol), or its monoethyl ether, should be used instead because they are less readily autoxidized. They do not stain the fingers, and their reduction potentials are only slightly inferior to that of pyrogallol itself.

420. Aminophenols. The aminophenols are amphoteric substances, acids by virtue of being phenols and bases by virtue of their amino group or groups. The acid properties are manifested chiefly when they contain two hydroxyl ($-\text{OH}$) groups. Thus, while in all cases the monophenolate is formed in the presence of caustic alkalis, the carbonate alkalis only give the phenolate in the case of the aminodiphenols, e.g. diaminoresorcinol. The aminophenols are only stable in the form of a salt (hydrochloride, sulphate, oxalate) the free base being rapidly oxidized in air. It is these salts which usually comprise the commercially available developing agents. The following table shows the weights of various alkalis necessary to neutralize the acid and form the free base of the aminophenol. For convenience, the diamine paraphenylenediamine hydrochloride is included in this table. The quantities of carbonate, borax, and trisodium phosphate correspond to the amounts required to form the bicarbonate, boric acid, and disodium hydrogen phosphate respectively.

Weight of the Various Alkalis needed to liberate 100 g of Free Base.

	Paraminophenol Hydrochloride Oxalate	Metol sulphate	Parapheny- lenediamine hydro- chloride
Weight of Developer Salt used	133.5	142	140
Sodium hydroxide	36.8	32.6	37.2
Potassium hydroxide	51.4	46.6	51.9
Sodium carbonate, anhydrous	97.2	86.2	98.2
Potassium carbonate anhydrous	126.5	112.2	127.7
Borax	174.7	154.6	176.6
Trisodium phosphate	174.3	155	177

Paraminophenol. The hydrochloride of paraminophenol $1 : 4 - \text{C}_6\text{H}_4(\text{OH})(\text{NH}_2, \text{HCl})$, molecular weight 145.6, was recommended as a

developing agent by A. and L. Lumière and by M. Andresen in 1891. It appears in the form of white, or grey, crystalline needles, which decompose before melting. It is very soluble in water (about 25 per cent at 15°C), less soluble in alcohol, and insoluble in ether. The free base is much less soluble in water (about 1 per cent at 15°C) and in solutions of sulphite and carbonate. It is very soluble as the phenolate in the presence of caustic alkalis, and this property is made use of in the preparation of very concentrated developers which are diluted 20 to 100 times for use. The addition of an alkali carbonate to a solution of the hydrochloride is accompanied by effervescence and the precipitation of the free base. Particularly in the United States, paraminophenol is sometimes sold as the oxalate (Kodolon). J. Desalme, 1924, has suggested that the tartrate should be used, in which case the free base is not precipitated on adding carbonate.

Metol. Metol, also known as Genol, Rhodol, Viterol, Elon, Monol, Scatol, Satrapol, Pictol, Atolo, etc., is the sulphate of N-methylparaminophenol, $\text{CH}_3\text{NH} \cdot \text{C}_6\text{H}_4 \cdot \text{OH}$, $\frac{1}{2} \text{H}_2\text{SO}_4$, molecular weight = 172. It was first prepared and recommended by A. Bogisch in 1891. It takes the form of small colourless plates which decompose before melting, and which are soluble in water (4.5 per cent at 15°C) and in alcohol, and insoluble in ether.

On adding carbonate to a concentrated solution of metol, the free base is precipitated, as it also is when sodium sulphite is added. The free base melts at 85°C . It is soluble in alcohol, ether, and acetone, and in strongly alkaline aqueous solutions.

After considerable aerial oxidation a sulphite solution of metol appears brown with a blue fluorescence. On exposure to air, an alkaline solution of metol (without sulphite) turns rapidly, through yellow, to a dark brownish-violet colour as the result of the formation of polymerized oxidation products.

Metol can develop when dissolved in a plain sulphite solution, but it is made much more active on adding alkali. At high pH values, when a caustic alkali is used, the reduction potential is very high and the tendency to give fog necessitates the use of bromide. Contrary to a widely held opinion, metol developers (without hydroquinone) will give gamma values as high as other developers, providing that the development is sufficiently prolonged. Metol is often used in association with hydroquinone (§ 419).

The dermatitis which metol developers cause

on the skin of allergic users is occasioned by traces of dimethylparaphenylenediamine sometimes present as an impurity in the metol.

Glycin. Glycin, which differs from the aminophenols referred to above in that it is an amino acid and exists without added acid as an internal salt, is parahydroxyphenylaminoacetic acid, $C_6H_4(OH)NH \cdot CH_2COOH$, molecular weight = 167. It is known also as Iconyl, Glyconiol, Kodurol, Monazol, or Athenon. Glycin, which was introduced by Bogisch (1891) appears in the form of colourless brilliant plates which decompose at about 200°C. It is almost insoluble in water (0.23 per cent at 15°C). It is insoluble in alcohol and in ether, while it is soluble in dilute inorganic acids, and in mildly alkaline solutions of carbonate and sulphite. It is very soluble in solutions of caustic alkalis.

An important characteristic of glycin is that it is only very slowly oxidized by air, either in the dry state, or in even very dilute alkaline solution. It is well suited for prolonged developments. It has been used for the development of motion picture films on continuous processing machines in which the developer is agitated by bubbles of compressed air, and in development on a rotating partially immersed drum.

Potassium carbonate is better than sodium carbonate as the alkali for glycin developers because it allows the preparation of more concentrated stock solutions.

421. Diaminophenol. By virtue of its two amino groups, diaminophenol can develop rapidly in a plain sulphite solution. The developer thus obtained has a very high reduction potential.

The dihydrochloride of 2 : 4-diaminophenol, $C_6H_4(OH)(NH_2)_2 \cdot 2HCl$, molecular weight = 197, known also as Amidol, Diamol, Dolmi, Acrol, etc., was introduced by A. Bogisch in 1891. It appears usually as light or dark grey needles, which, on heating, decompose before melting. It is very soluble in water (25 per cent at 15°C), and it is precipitated from its concentrated aqueous solution by an excess of hydrochloric acid. It is almost insoluble in alcohol and in ether. It is very soluble in sulphite solutions, the sulphite being transformed in part into bisulphite. This developer oxidizes fairly rapidly in air and, for this reason, should be prepared immediately before use. On adding alkalis to this solution the oxidation is greatly accelerated and a deep violet discoloration appears. If, on the other hand, a weak acid is added (bisulphite, or boric, lactic, or glycolic acids) the solution becomes

much more stable and the developer can be held for several days in a dish.

It has been suggested that amidol developers can be stabilized by the addition of 1 to 2 g per litre of metol or hydroquinone, which do not affect the photographic behaviour at this low level of alkalinity. Again Desalme found (1921) that amidol developers could be stabilized by the addition of tin salts, e.g. sodium stannotrate.

When an amidol developer is acidified to the point where there is no longer any neutral sulphite in solution, it acts as a depth developer, the development commencing at the bottom of the emulsion layer (§ 390). Amidol developers give a neutral grey image. The solution tends to stain the skin and nails.

422. Phenylenediamines. Paraphenylenediamine or 1 : 4-diaminobenzene, which was first proposed by M. Andresen in 1888, is marketed either as the free base or the dihydrochloride, $C_6H_4(NH_2)_2 \cdot 2HCl$, molecular weight = 181. The base appears as crystalline platelets which, though colourless when very pure, are usually light grey in colour. The base melts at 140°C, is slightly soluble (3.7 per cent at 15°C) in water, and is soluble in ether and alcohol. The aqueous solutions have a definite solvent action on silver bromide. The dihydrochloride appears as fine, grey (colourless when pure) crystalline tablets which decompose before melting. It is soluble in water, slightly soluble in alcohol, and insoluble in ether and in concentrated hydrochloric acid.

In plain sulphite solution, paraphenylenediamine develops very slowly, only reducing a part of each grain, thus giving images of low contrast with very low granularity. Materials destined for development in such paraphenylenediamine solutions should be considerably overexposed, judged by normal standards. Better contrast can be obtained by adding borax or an alkaline carbonate to the developer, but development is still very slow and tends, often, to give rise to some dichroic fog. If, however, the sulphite solution of paraphenylenediamine is made alkaline by a caustic alkali, a rapid developer of high reduction potential is obtained. Even with a low concentration of sulphite this developer keeps quite well. Its oxidation products are colourless.

The rate of development is increased by all circumstances which decrease the concentration of the oxidation products. In the present case this can be brought about by an increase in the alkalinity, which accelerates the spontaneous

decomposition of the oxidation products of paraphenylenediamine, and by the presence of agents which couple with the oxidized phenylenediamine (T. H. James, 1939).

The activity of phenylenediamine developers is considerably enhanced by the addition of thiocyanates (or sulphocyanides) in a concentration of about 1 g per litre (L. D. Mannes and L. Godowski, 1935).

The dimethyl- and diethylparaphenylenediamines and particularly paraminodimethylaniline, $C_6H_4 \cdot NH_2 \cdot N(CH_3)_2$, $2HCl$, which are more soluble than the non-alkylated compound, and less readily oxidized in air, give energetic and stable developers on being made alkaline by sodium carbonate. These developing agents are much used in colour development. However, these agents are very harmful to the skin.

A very soluble derivative which does not attack the skin is N- β -methylsulphonamidoethyl-4-aminoaniline (NH_2) C_6H_4 (NH \cdot C_2H_4 \cdot NH \cdot SO $_2$ CH $_3$). This and some homologues have been proposed for colour development in the presence of sulphite and carbonate (A. Weissberger, 1939).

Orthophenylenediamine, or 1 : 2-diaminobenzene, $C_6H_4(NH_2)_2$, molecular weight = 108, is similar to the para isomer in its properties. However, it is less harmful to the skin and is used in a number of proprietary fine-grain developers.

423. Developer Dermatitis. While the impurities found in metol are present only in sufficient concentration to cause dermatitis in allergic subjects, whose susceptibility is greatly increased after a first attack, the continual handling of paraphenylenediamines, especially the dimethyl- and diethyl-homologues, results invariably in dermatitis unless suitable precautions are taken.

It is usually recommended that the hands should be rinsed in dilute hydrochloric acid after handling the developing agents in the dry state or in solution. The acid (2 ml of concentrated acid per 100 ml) should be situated permanently in a bowl near to the developing dishes. The effectiveness of this precautionary measure is probably due to the phenylenediamines being innocuous in the form of the hydrochloride (J. Southworth, 1938). This treatment is advantageous also in that it helps to avoid staining of the hands.

The wearing of rubber gloves is recommended when handling the alkylated phenylenediamines, especially for operators who have had a previous attack of dermatitis. However, the wearing of

rubber gloves induces sweating and some skin troubles can arise if the gloves are not frequently washed and dried.

Various ointments have been suggested to protect the skin while handling developers, but they are often too greasy and fluid. The following mixture, which is solid below 90°C has been devised by G. D. Hiatt (1939). A mixture of 33 parts of olive oil and 22 parts butyl stearate is heated to 130°C. Eleven parts of cellulose butyrate (56 per cent butyryl) are added and dissolved by raising the temperature to 170°C. After cooling to 150°C, 33 parts of zinc oxide are added. The cold mixture can be rubbed easily on the skin.

In the event of an outbreak of dermatitis it is best to consult a medical practitioner. However a method of treatment (A. Jourdan, 1935) which has often given excellent results is as follows. The affected part is bathed for 2 hours a day in water as hot as can be tolerated. The itching stops after the first day, healing starts on the third day, and recovery is often complete in about a week.

424. Alkalies. Sodium hydroxide, or caustic soda, NaOH, molecular weight = 40, is usually obtainable in the form of waxy-white flakes, pellets, or small sticks, and as a concentrated solution or lye. It is available in various grades of purity, though most of the grades, if clean and white, will serve for photographic solutions. The ordinary grade usually contains from 2 to 7 per cent of sodium carbonate, the actual proportion depending upon the degree to which it has been exposed to the atmosphere. It also contains a small proportion of sodium chloride. Since sodium hydroxide is strongly deliquescent, the solid usually contains a small quantity of absorbed water.

Sodium hydroxide solutions are extremely caustic, especially when warm or hot, and care should be taken when handling them to protect the skin and eyes. Protective goggles should be worn and any splashes on the skin or clothing should be washed immediately with plenty of water.

To prevent the absorption of moisture and carbon dioxide from the atmosphere, solid sodium hydroxide should be stored in tins or plain iron drums with well fitting lids. Neither the solid nor its solutions should ever be stored in glass containers with ground-glass stoppers because these inevitably become jammed in use.

A considerable quantity of heat is evolved when sodium hydroxide is dissolved in water.

For this reason, cold water should always be used and the sodium hydroxide introduced slowly, while the solution is constantly stirred. Without these precautions the solution may boil with explosive violence, and the intense local heating may fracture a glass or ceramic container.

Sodium hydroxide solutions rapidly dissolve aluminium, zinc, and tin and should not be allowed to come into contact with these metals or tinned and galvanized iron.

Potassium hydroxide, or caustic potash, KOH, molecular weight = 56, is very similar in its properties and appearance, etc., to sodium hydroxide and all the above remarks on sodium hydroxide apply equally well to the potassium compound.

Lithium hydroxide is only infrequently used in photography because of its comparative rarity. It appears in commerce usually as the crystalline hydrate $\text{LiOH} \cdot \text{H}_2\text{O}$, molecular weight = 42, which has the advantage of being non-deliquescent. While the sodium and potassium hydroxides are soluble in water in all proportions, lithium hydroxide is only soluble to the extent of about 15 per cent.

Ammonium hydroxide, or "ammonia," is considerably less basic than the alkali metal hydroxides. It is formed on dissolving ammonia gas, NH_3 , molecular weight = 17, in water. The gas tends to leave the solution and some is lost each time the bottle is opened. The alkaline properties of the solution result from the presence of ammonium hydroxide, NH_4OH , molecular weight = 35. The following table gives the specific gravity of various ammonia solutions. The concentrated solution usually obtainable should have a specific gravity of 0.88.

Specific Gravity at 15°C	0.958	0.924	0.895	0.882
Percentage of NH_3	10	20	30	35

Crude solutions of ammonia are contaminated by various salts (carbonate, chlorides, sulphates, sulphides) and nitrogenous organic bases, particularly pyridine.

Care should be exercised when handling concentrated ammonia solutions, especially when opening bottles, to prevent accidents through inhaling the concentrated vapour. Ammonium hydroxide dissolves silver chloride and bromide freely but will dissolve only a trace of silver iodide.

Dilute (3 per cent NH_3) ammonium hydroxide dissolves silver chloride to the extent of about 1.3 per cent. A stronger solution (15 per cent NH_3) will support up to 7.5 per cent silver chloride and 0.1 per cent silver bromide.

Triethanolamine. Triethanolamine $\text{N}(\text{CH}_2 \cdot \text{CH}_2\text{OH})_3$, molecular weight = 149, was suggested for use as an alkali in fine-grain developers by M. L. Dundon in 1932, and in colour developers by E. E. Jelley in 1938. The commercial liquid is yellowish and viscous, with a very faint ammoniacal odour, and usually consists of a mixture of 80-85 per cent triethanolamine, the remainder being di- and monoethanolamine. This liquid, of specific gravity 1.12 at 20°C, is more basic than ammonia but is neither caustic nor irritant. It has no action on gelatine nor on the support of films. It has a lower solvent action in silver halides.

It should be stored in well-stoppered bottles, because it absorbs moisture and carbon dioxide, and slowly turns brown in contact with air.

425. Alkaline Carbonates. *Sodium carbonate* is supplied in several forms. *Anhydrous sodium carbonate*, Na_2CO_3 , molecular weight = 106, appears as a white powder in either a dense or a light form, the light form being more common. The monohydrate, $\text{Na}_2\text{CO}_3 \cdot \text{H}_2\text{O}$, molecular weight = 124, takes the form of stable, colourless crystals similar in appearance to granulated sugar. It is sold in various grades, the crystals varying from about 1 to 5 mm across. The monohydrate is known also as *crystal carbonate* (not to be confused with sodium carbonate, crystalline, below). This form is more common in photographic work in the United States, although it is manufactured in Great Britain, too. The last, and most common, of the carbonates that are used in photography is the decahydrate, $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$, molecular weight = 286, which is the usual *sodium carbonate, crystalline* which, in its crude form, is known as *washing soda*.

When fresh, the anhydrous salt contains 98 per cent of sodium carbonate, but it slowly absorbs moisture and carbon dioxide forming the bicarbonate. If anhydrous sodium carbonate is spread in a thin layer in moist air, it will, after 15 days, contain 20 to 25 per cent of bicarbonate.

The monohydrate is the stable form. Anhydrous sodium carbonate tends to pick up moisture and the decahydrate to lose water of crystallization, to form the monohydrate. When fresh it contains no bicarbonate and has little tendency to absorb carbon dioxide.

The decahydrate is efflorescent. Of the two forms, the anhydrous and the decahydrate, the anhydrous is to be preferred because the efflorescent decahydrate loses moisture more rapidly.

than the anhydrous tends to gain it, and so is more likely to cause errors.

The pure, anhydrous, monohydrated, and decahydrated forms may be interchanged in the proportions shown in the following table.

	Anhydrous	Monohydrate	Decahydrate
Anhydrous	1.00	0.85	0.37
Monohydrate	1.17	1.00	0.43
Decahydrate	2.70	2.25	1.00

Sodium carbonate is quite soluble in water. At 15°C the saturated solution contains about 16 per cent of the anhydrous salt, the concentration reaching 36 per cent at 30°C.

Potassium carbonate is usually obtained in the anhydrous form, K_2CO_3 , molecular weight = 138, as a white deliquescent powder which should be stored in a well-sealed container. It absorbs moisture and carbon dioxide very readily to form the bicarbonate and, unless a specially purified sample is obtained, most specimens contain a considerable proportion of the bicarbonate. At 15°C the saturated solution contains 81 g of potassium carbonate per 100 cc. At equal concentrations potassium carbonate renders a developer more alkaline than does sodium carbonate.

Ammonium carbonate. The ammonium carbonate used in some developers for warm-tone prints is not the normal carbonate $(NH_4)_2CO_3$, but the sesquicarbonate $(NH_4)_2CO_3 \cdot 2(NH_4)H \cdot CO_3$, H_2O , molecular weight = 272. Ammonium sesquicarbonate appears as fibrous lumps having an ammoniacal odour. It usually contains a considerable proportion of ammonium carbonate. It should be stored in tightly stoppered containers. If the crystals of ammonium sesquicarbonate are covered with a white crust, it should be removed by rinsing briefly, and then blotting off the moisture before weighing. This salt, which is very soluble in cold water (about 25 per cent) is decomposed on heating.

426. Various Alkaline Salts. *Sodium phosphates*. Sodium orthophosphate, $Na_2PO_4 \cdot 12H_2O$, molecular weight = 380, also known as tribasic sodium phosphate, appears usually as white, efflorescent crystals. It is very soluble in water (20 per cent at 15°C), and is more basic than the carbonate, at equal concentrations. The industrial product usually contains an excess of sodium hydroxide.

Sodium pyrophosphate, $Na_4P_2O_7 \cdot 10H_2O$, molecular weight = 446, has been suggested (W. H. Wood, 1939) as a moderate alkali for fine-grain developers.

Sodium borates. Two sodium borates are used. The *metaborate* is sold as the tetra- and octahydrates, $Na_2B_4O_7 \cdot 4H_2O$, molecular weight = 203.7, and $Na_2B_4O_7 \cdot 8H_2O$, molecular weight = 275.7. Sodium metaborate is fairly basic.

Borax, which is feebly alkaline, is the tetra- or pyroborate, $Na_2B_4O_7 \cdot 10H_2O$, molecular weight = 381.

Sodium metaborate is very soluble in water (33 per cent at 19°C). The crystals are efflorescent, so they should be stored in a closed container to avoid loss of water vapour as well as to limit the absorption of carbon dioxide. The equivalent of 100 g of sodium metaborate ($4H_2O$) can be obtained in solution by adding 14.5 g of sodium hydroxide to a solution containing 69 g of borax, providing that the borax and sodium hydroxide are pure.

This salt, like sodium orthophosphate, has the advantage of yielding developers whose alkalinity is intermediate between that of carbonate and caustic solutions. Unlike sodium carbonate, sodium metaborate does not give rise to bubbles of gas on being carried into an acid solution, so there is no danger of the occurrence of gas blisters in the emulsion when an acid stop bath or fixer is used directly after development. Again metaborate is to be preferred to orthophosphate because the latter tends to cause a precipitate when carried into fixing baths containing alum (§ 492).

Borax is generally supplied in the form of a fine, white, efflorescent, crystalline powder. It is only moderately soluble in water (2 per cent at 15°C). It should be stored in a well stoppered container to avoid loss of water of crystallization and the errors in weighing that would result.

Borates should not be used in developers containing catechol or pyrogallol because, with boric acid, these form strongly acid complexes of poor developing activity.

Various. Of the other alkaline salts that have been used in developers, sodium aluminate (J. R. Allburger, 1939) and sodium metasilicate (H. D. Russell, 1936) may be noted.

427. Practical Equivalence of the Usual Alkalis. At equal concentrations expressed in grammes per litre, sodium and potassium salts are practically interchangeable. It is only in this case that two alkalis can be substituted for each other in proportions that correspond to the same neutralizing capacity. Concerning alkalis, there is no relationship between equivalent quantities in a developer and quantities equivalent in the sense that they liberate the same amount of

heat when they are neutralized by the same acid. It has already been mentioned that in a fresh negative developer there is equivalence between alkalis that bring the bath to the same pH value (§ 293), but without the presence of buffers to ensure constancy of pH, it is impossible to envisage any practical equivalence between, for example, carbonates and caustic alkalis. A sodium carbonate solution containing 21.2 g

sodium sulphite, (c) to one of the forms of bisulphite, (d) and (e) to sodium hydrosulphite, (f) and (g) to sodium thiosulphate.

The co-existence of the sulphinic (a) and sulphonic (b) forms of sodium sulphite is illustrated by the fact that different substances are obtained when sodium bisulphite is neutralized by potassium hydroxide, than when potassium bisulphite is neutralized by sodium hydroxide.

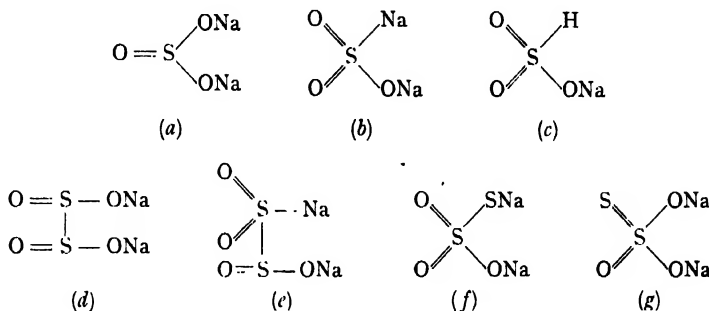


FIG. 28.12. STRUCTURAL FORMULAE FOR SODIUM SULPHO-SALTS
(a, b) Sulphite (c) Bisulphite (d, e) Hydrosulphite (f, g) Thiosulphate

(anhydrous) per litre has a pH of 11.0, a value which would be reached by a concentration of sodium hydroxide of 0.13 g per litre, a quantity that would very rapidly become neutralized and would thus become useless in facilitating development. A suitable buffer allows the amount of available alkali to be increased while maintaining the pH of the bath at a relatively low and almost constant level.

The rule that alkalis can be interchanged at equal pH values must not be considered as being absolute. For example, a developer having a high concentration of sodium orthophosphate, because of its high viscosity, will penetrate into the emulsion layer much more slowly than one brought to the same pH by sodium metaborate. For this reason, and because the rates of change of solution at the emulsion surface would be less in the more viscous solution, development would be slower in the phosphated developer.

428. Sulphites. Many of the properties of the sulphites, as well as of the hydrosulphites (thionites), and thiosulphates, are difficult to explain unless the fact is taken into account that each of these salts has two tautomeric forms which coexist in equilibrium in solution. The various structures are schematized in Fig. 28.12. Formulae (a) and (b) correspond to

Various organic derivatives are known corresponding to the two forms.

Sodium sulphite. Sodium sulphite is the salt that is usually used in developers. The potassium salt is very rarely used. Sodium sulphite is supplied in the anhydrous state, Na_2SO_3 , molecular weight = 126, or as the crystalline septahydrate $\text{Na}_2\text{SO}_3 \cdot 7\text{H}_2\text{O}$, molecular weight = 252. One g of the anhydrous salt is thus equivalent to 2 g of the hydrate, providing both are pure.

The anhydrous salt is a fine, dense, white powder which, by settling down into a close-packed form, protects itself against the action of the air. The hydrate appears as small, colourless, efflorescent crystals which are often covered by a powdery coat of the anhydrous salt. The proportion of sodium sulphite in the anhydrous product is usually greater than 90 per cent. The hydrate contains between 40 and 45 per cent of sodium sulphite (anhydrous). Both products contain small proportions of sulphate and dithionate arising from oxidation, together with some carbonate, chloride, and traces of thiosulphate. Sodium sulphite should be stored in closed containers.

Sodium sulphite is very soluble in water (about 15 per cent anhydrous at 20°C). While the hydrate cools the solution on dissolving, the

anhydrous salt causes no change in temperature and for this reason is to be preferred when the developer is made up immediately before use.

Solutions of sodium sulphite are alkaline towards litmus, which is turned blue. The oxidation of sulphite solutions is very slow at pH greater than 9.6 (T. H. James and A. Weissberger, 1939). The rate of oxidation of the neutral solution is decreased greatly by traces of hydroquinone or paraminophenol, and by alcohols, glycerine, mannite, or ordinary sugar. Stock solutions of sulphite should not be made up to last for periods greater than one week.

The addition of acids causes the formation of bisulphite and sulphurous acid, and the solution tends to lose sulphur dioxide (SO_2).

The sulphites form complexes with the salts of various heavy metals. Sodium sulphite solutions dissolve silver chloride and bromide, an 8 per cent sulphite solution dissolving 0.08 per cent of silver bromide. The solution slowly deposits colloidal silver and sodium dithionate is formed. Calcium sulphite is insoluble and gives rise to the whitish sludge which slowly settles from developer solutions made up from hard water (§ 289).

429. Sodium Bisulphite. Sodium bisulphite, or sodium acid sulphite, NaHSO_3 , molecular weight = 104, is obtainable as a white powder, similar in appearance to sodium sulphite and containing about 80 per cent of available bisulphite.

The solutions of sodium bisulphite have the properties of a mixed solution of sodium sulphite and sulphur dioxide (sulphurous anhydride). Sulphur dioxide is freely emitted from the solution on exposure. In solution sulphur dioxide forms sulphurous acid and it is this that reduces solutions of chromates and permanganates. Bisulphite solutions dissolve silver bromide and chloride in the same way as sulphite solution.

Bisulphite solutions should not be allowed to come into contact with zinc, galvanized iron, or other easily oxidized metals, because, in the presence of these, hydrosulphite is formed which tends to cause a heavy fog or stain.

Bisulphites, which are added to the part of a two-solution developer containing the alkali, will neutralize some of the alkali when the two parts are mixed. Account should be taken of this fact when devising the formulae of the two parts. When a caustic alkali is used, the bisulphite is transformed into sulphite. When an

alkali carbonate is used the bisulphite is converted to sulphite with the formation of an equivalent amount of bicarbonate.

Potassium metabisulphite. Potassium metabisulphite, or pyrosulphite, $\text{K}_2\text{S}_2\text{O}_5$, molecular weight = 222, takes the form of large colourless crystals. These are quite stable, but over a long period may become covered with a crust of potassium sulphate and dithionate. Potassium metabisulphite is fairly soluble in water, the resulting solution containing the bisulphite, KHSO_3 . The solution should be prepared in the cold, all the bisulphite solutions being decomposed, through loss of sulphur dioxide, on heating.

430. Alkali Bromides. **Potassium bromide** forms small anhydrous crystals, KBr , molecular weight = 119, colourless or white, cubical in shape, very soluble in water (over 60 per cent at 60°F), insoluble in alcohol; the chief impurity is potassium chloride, which, however, does not interfere with the action of the bromide. Potassium bromide is a perfectly stable salt.

Sodium Bromide. Sodium bromide is a very deliquescent salt, of very variable composition. It is appreciably cheaper than potassium bromide, but can only be used where sufficient quantities warrant the trouble of ascertaining the quantities to be used, the salt being made up into stock solutions as soon as purchased.

Ammonium Bromide. This occurs in the form of small colourless crystals of anhydrous salt (NH_4Br), which is slightly deliquescent, and turns yellow on long exposure to light. It is even more soluble in water than potassium bromide and is slightly soluble in alcohol. It slowly decomposes at boiling point. It is used in some formulae for warm-tone developers.

PRACTICAL NOTES

431. Qualities Desirable in a Developer. The qualities demanded of a developer vary somewhat according to the results required, and according to the method of use.

In all cases, the developer should cause no more than a moderate degree of swelling of the gelatine emulsion. It should not oxidize rapidly in contact with air, and it should have a low tendency to cause fog or stain on sensitive materials. It is advantageous if the rate of change of gamma with time is slow in the region of the desired gamma value.

According to the work in hand, the developer should be capable of developing the shadow details without it being necessary to proceed to a

high gamma value; or, it should be capable of giving images of the finest possible granularity without having to compensate for the incomplete development by giving a considerable over-exposure; or, on the other hand, it should give the maximum contrast so that low exposures are not developed in order that the effects of irradiation or reflections may be eliminated in the copying of subjects containing only black and white tones. It may be necessary to examine the image after the shortest possible delay without sacrificing to any great extent the gradation of the image or the shadow detail.

In an industrial, or semi-industrial establishment, economic considerations are more important than they are in the darkroom of the amateur, the portraitist, or the scientific worker. The cost of development per unit area of processed material should be as low as possible, consistent with a perfect regularity of results, whence it is required to maintain the developer at constant activity for a long period to make the best use of constituents.

432. The developer should not be used at an unnecessarily high concentration because this leads to waste of chemicals even when the bath is used to the point of complete exhaustion. The sensitive material, even after draining or squeegeeing, carries an appreciable quantity of solution out of the bath, and this is more costly if the bath is more concentrated. The developer carried over will, if more concentrated, more rapidly neutralize the stop bath and make it necessary to re-acidify the fixing bath more frequently.

When working to low gamma values, the developer should be sufficiently dilute to avoid the necessity for very short times of development which often result in local irregularities in development. As a general rule, the concentration of the developer should be adjusted to give a development time of 5 minutes in dish development or 20 minutes in tank development.

On the other hand, too great a dilution of the developer should be avoided because, in this case, the exhaustion is too rapid and it is difficult to maintain the bath at constant activity.

It should be remembered that a very dilute developer gives rise to a greater fog density than would be obtained in a quicker-acting developer.

433. *Formulae for Developers.* Some photographers spend most of their time testing successively all the developing formulae that they see, even when they show but negligible

differences from other formulae previously tried (differences of the same order as those resulting from the uncertainty regarding the actual content of active substances in the products used). They attribute the success of other workers to the possession of some ideal formula, kept jealously secret, and making good all the failings of the photographer.

Except for some very special purposes, which require the use of developing baths of a composition considerably different from those of the usual type, any good formula is as suitable as another, and the best are generally not the most complicated. The choice between various current formulae should be made more on account of cost than for technical reasons. It has often been said that the best developer is the one with which the photographer is familiar, and it is not by abandoning one formula for another at the moment that its use is becoming familiar that the best results can be hoped for.

Some ridiculous formulae have been published owing to mistakes in converting foreign weights and measures or to typographical errors. Chance coincidences have led some practical workers, with little experience of experimental methods, to recommend the addition of products which are completely useless. Putting such exceptions aside, success depends more on the judicious conduct of the operations than on the choice of a particular formula.

434. *The Swelling of Gelatine.* The hard gelatines used in the manufacture of emulsions absorb comparatively little water, the amount depending upon the degree to which they were hardened before coating. On an average, at about 15°C, the gelatine of photographic emulsions absorbs about 7 times its own weight of plain water after 10 minutes' immersion.

The swelling of gelatine prepared by an alkaline process is least in a weakly acid medium (pH about 4.6) corresponding to the *isoelectric point* of the gelatine (the gelatines obtained by an acid process usually have a much higher isoelectric point at pH 7 to 8). In an acid solution of pH lower than the isoelectric point, the gelatine, which is an amphoteric substance (§ 191), combines with acids by virtue of its amino groups. In an alkaline solution, on the other hand, it combines with the alkali through its acid groups. On the acid side, the swelling reaches a maximum between pH 2.5 and 2.7. On the alkaline side, the swelling increases steadily and becomes considerable in dilute solutions of caustic alkalis at about pH 12.

The swelling is much limited by the presence in solution of salts at a relatively high concentration. Thus, there is not much swelling in a 15 per cent solution of sodium carbonate, the gelatine absorbing only half its own weight of solution in spite of the high pH value. Even in a 5 per cent sodium carbonate solution it swells to a lesser extent than in plain water. As will be seen below, a swollen emulsion can be dried almost instantaneously by immersing it in a very concentrated salt solution (§ 521).

The swelling is considerably increased on warming the solution which may cause an irreversible deformation of the gelatine.

The gelatine is attached to a non-stretching support and can only swell in a direction perpendicular to it. When the swelling is excessive, the tangential forces are great and can cause the gelatine to separate from the support or, if the adhesion is sufficiently great, the gelatine reticulates.

435. In the course of the usual processing, a photographic emulsion passes, in succession, through an alkaline developer, the rinse water, an acid fixer, and the final wash water. Thus the gelatine is alternately swollen and contracted, which puts its strength to a severe test (S. E. Sheppard, 1928).

Unless the developer contains a relatively high concentration of salts (sulphite, carbonate, and sometimes sulphate), there is a danger that the swelling will be unlimited and will cause a disintegration of the gelatine.

These conditions tend to be produced, especially at high temperatures, in a very dilute developer by the low salt concentration as well as by the prolonged time of immersion in the bath.

By lowering the salt concentration, rinsing (after development) considerably increases the swelling. The swelling is abated in the acid fixer, but it is increased anew in the final washing. The danger of damage is increased when the various baths are at very different temperatures.

436. **Methods of Agitation.** The layer of liquid in direct contact with the emulsion, in which the developer oxidation products accumulate after diffusing out of the emulsion, is very adherent and can only be displaced by a sufficiently vigorous agitation. A simple displacement of the sensitive material relative to the solution in the bath only serves to slide this layer along the emulsion surface without removing it.

In the case of dish development, rocking the

dish, if it does not achieve uniformity of development, is sufficient to avoid the deleterious effects of exhaustion products (§§ 395-7). Use can be made of rocking devices, moved by clockwork or by an electric motor, to rock the bath automatically during development. If such an arrangement is employed, care must be taken to have a comparatively long period of oscillation. Too rapid rocking may produce stationary waves which can cause the image to show alternate vignetted bands of greater and less development.

In scientific work where perfect uniformity is desirable, the exhaustion products can be removed, as fast as they are formed and diffuse out, by passing a velvet covered roller over the emulsion surface in all directions (O. Bloch, 1921), or a large brush (W. Clark, 1925) that can be made by stretching a piece of chamois leather along the edge of a glass plate, or, finally, by a to-and-fro motion of scraper blades set at an angle of 45° to the direction of travel with a clearance of 0.5 mm between their edges and the emulsion surface.

When developing plates or films in holders in a vertical tank, the agitation can be effected by oscillating the holders vertically by hand or automatically. Furthermore, the bath can be circulated by an external pump or by the rapid rotation of an Archimedean screw inside a tube, open at both ends and shorter by a few centimetres than the depth of the developer.

In development on continuous processing machines, fixed scraper blades can be situated obliquely at a distance of about 1 mm from the surface of the film. The developer solution, drawn from the tank by a pump, can be impinged on the emulsion surface by submerged jets situated in staggered formation along the film path. In machines in which the loops of film are immersed in tubes, the developer can be agitated by bubbles of gas. The use of an inert gas would be rather expensive, and for this reason the use of compressed air has been adopted, especially for use with glycin developers. In the case of developers that are more readily oxidized by air, such as metol-hydroquinone positive developers, or metol negative developers, too high a rate of oxidation can be avoided by increasing somewhat the sulphite concentration (J. I. Crabtree and C. H. Schwingel, 1940). The developing tubes should be sufficiently extended to prevent the foam that is created by the bubbling from spilling over. The formation of the foam helps

to clarify the bath (C. E. Ives and C. J. Kunz, 1940; C. R. Davies, 1940; A. Lovichi, 1944).

Various types of machine have been devised for the development of sensitometric exposures (L. A. Jones, M. E. Russell, and H. R. Beacham, 1936). Such machines would be well suited to the development of all photometric negatives.

437. Exhaustion of the Developer. When a developer is used continuously, part is carried away by the plates and films that are removed from the tank. The volume thus removed varies from 1 to 5 ml per square decimeter ($\frac{1}{4}$ – $\frac{1}{2}$ oz per sq ft) of emulsion surface, the precise rate depending upon the degree of swelling of the gelatine and on the efficiency of draining or squeegeeing. On an average the rate of carry-over is 2.25 cc per square decimeter ($\frac{1}{2}$ oz per sq ft). A rubber roller squeegee, or a compressed air knife is used to limit the carry-over on continuous motion-picture processing machines.

The concentration of active products in the remaining developer is decreased, while the concentration of bromide is increased. When the sensitive materials are wetted before development, the developer is diluted by the water that is carried in. Cellulose-acetate film supports tend to adsorb a small quantity of the developing agents. Finally, the action of the air converts some of the developing agents to sulphonates both while the bath is being used and in the intervals between use.

When a metol-hydroquinone developer is aerially oxidized, 10 times more hydroquinone than metol is consumed and the pH of the solution is increased. On the other hand, 10 times more metol than hydroquinone is oxidized during development in a developer of low pH, with a decrease in the pH (R. M. Evans and W. T. Hanson, 1938). In consequence of this, it is impossible to assess the degree of exhaustion of the developer just by measuring the pH.

When a large number of exposures are successively developed in a comparatively small volume of developer, it has been found that in order to maintain a constant gamma value it is necessary gradually to increase the time of development. The emulsion speed falls gradually but more rapidly as the exhaustion proceeds, as a result of the sulphite dissolving a greater quantity of silver bromide as the time of development is prolonged.

The loss of speed would be considerable, and intolerable, if the time of development were not increased so as to obtain the same gamma value each time. It is less important when the

chosen gamma is high, and this is one reason why a gamma of about 1.1 (§ 444) is recommended for the development of roll-films, other than miniature films. This mode of exhausting a developer is especially suited to the development of radiographs, where development is prolonged sufficiently to obtain almost the maximum gamma (γ_{∞}).

438. Maintaining a Developer at Constant Activity. On removing from the tank or machine a volume of developer proportional to the total area of the sensitive material developed, and on topping up the remainder to constant volume by the addition of a suitable solution (replenisher solution), the composition of the bath rapidly tends towards an equilibrium. It would seem that, starting from the moment when this equilibrium is reached, the developer thus maintained might be used indefinitely. In fact, the equilibrium is not a true one and harmful deviations would be produced in the long run. Moreover, various impurities collect in the bath (reduced silver sludge, calcium sulphite sludge, gelatine and its degradation products, dust, coloured oxidation products liable to stain the gelatine, etc.). It is the rule, in large laboratories, to reject the entire bath at the end of each week and to clean and sterilize the installation (§ 410). In a smaller plant the period between installing and rejecting a bath can be considerably increased if, when the bath is not in use, it is covered by a floating lid (§ 276) to protect it from aerial oxidation.

In a vertical tank, the developer is replenished at intervals after developing a given area of material (e.g. a fixed number of spools), and on each addition of replenisher the bath is thoroughly stirred. Since this stirring is liable to disturb the sediment at the bottom of the tank, it has been recommended that the replenishment and stirring should be done at the end of the day's work so that the sediment can settle again overnight (J. I. Crabtree, 1937). In the case of developing machines, the replenishment is generally continuous and automatic. The point in the system at which the replenisher is added is a matter of some importance. In the motion picture industry, the replenisher solution, known as the "boost," is generally added into a reservoir where it is mixed with the developer solution that serves the processing machines, in order to ensure that the developer is of the same composition in all the machines, and to avoid the variations in activity that result from large variations in the average density of the

images being developed. In some systems where negative films are developed to a low gamma in slow working developers that are rich in sulphite, the replenisher solution is added at the point of entry of the film into the bath so that development is started in an almost fresh solution, thus reducing the loss of speed that is produced by starting development in the exhausted bath.

439. In order to maintain the bromide concentration in the bath at a constant level, it is necessary, in spite of the fact that the replenisher solution never contains bromide, to add the replenisher at a greater rate than the solution is carried over by the film leaving the bath. The surplus developer is allowed to overflow, or "bleed," at a suitable point in the system. In order to reduce to a minimum the loss of active chemicals, it is obvious that the developer should not be used at a concentration greater than necessary.

If the sulphite concentration is sufficiently high for its exhaustion to be negligible, the rate of consumption of the developing agents is not proportional to their initial concentration. Thus the proper formula for the replenisher might be quite different from that of the fresh developer. The optimum replenisher formula for a given developer can be found by systematic trial-and-error methods, the behaviour of the developer being frequently assessed by sensitometric tests (§ 443). However, such a method is lengthy, and during the trials some variations in the quality of the work can be expected. A method of systematic investigation involving a calculation of the equilibrium concentrations based on the data from some rapid *analyses* and sensitometric control has been described (R. M. Evans, 1938). The method is lacking in the determination of the alkalinity which, all other concentrations being maintained constant, is controlled by the *pH* value (as measured by a glass electrode). In order to minimize the variations of activity in a developer until the equilibrium conditions are reached, a very small quantity of iodide and an antifogging agent should be added to the fresh bath (§ 386) in quantities corresponding to those that are formed spontaneously in the course of development.

A developer that is replenished in this way must be controlled by frequent sensitometric tests and, in an industrial laboratory, by rapid analyses carried out alternately on the essential constituents. Such methods of control and analysis have been described by R. M. Evans

and W. T. Hanson, 1939; H. L. Baumbach, 1939; S. Bogdanov, 1939; R. B. Atkinson and V. C. Shaner, 1940, etc.

A marked increase in the concentration of sulphate, which is formed only by aerial oxidation, indicates an abnormal degree of aeration due, probably, to a defective pump. A progressive increase in activity indicates the excessive addition of replenisher solution possibly as the result of a leak in some part of the system.

The developers, and particularly the positive developers, should be rejected as soon as they become coloured, lest they stain the gelatine. The bubbling of an inert gas through the developer for about 15 minutes, produces an abundant foam and clarifies the developer, the coloured oxidation products and colloidal silver being carried away in the foam (M. Acribat, 1941).

It is necessary to mention that the rules for the maintenance of a given developer at constant activity fail when the sensitive materials are soaked in water before development, the volume of developer remaining constant. In such a case it is necessary to remove periodically a volume of developer proportional to the area of the film processed, or to the volume of the pre-bath carried over into the developer. The replenisher solution should be more concentrated than when the sensitive materials are introduced dry into the developer, in order to compensate for the dilution of the bath by the water carried in.

440. **Electrolytic Maintenance of a Developer at Constant Activity.** The industrial use of an equimolar mixture of sodium anthraquinone-2-sulphonate and of anthraquinone (green), in a solution buffered at *pH* 4 to 5, has been claimed by J. Rzymkowski (1938). The mixture is formed, and then maintained at constant activity by the cautious electrolysis of a solution of anthraquinonesulphonate. The developer, in which is immersed the cathode, is separated by a porous partition from the anode compartment which contains a solution of sodium hydroxide in which the bromide ions accumulate. The same method would be applicable to other quinones and to indophenols, indamines, etc., by choosing, as far as possible, an agent such that exhaustion would be shown by an appreciable change in colour, thus making it possible to regulate automatically the intensity of the current by a photoelectric cell.

441. **Method for the Comparative Testing of Two Developers.** The procedure generally adopted by photographers to compare two

developers consists in exposing two identical plates or films on the same subject with the same time of exposure; one of these is developed in each developer and the images so obtained are then compared. This method is not very satisfactory because it is not possible to place side by side the parts of the two negatives which

or a piece of sensitized paper, place in a printing frame at such a distance (determined by a preliminary trial) from a weak source of light that after two seconds' exposure a normally developed emulsion just shows a trace of image when compared with a portion which has not been exposed at all. An opaque card held in

Exposure

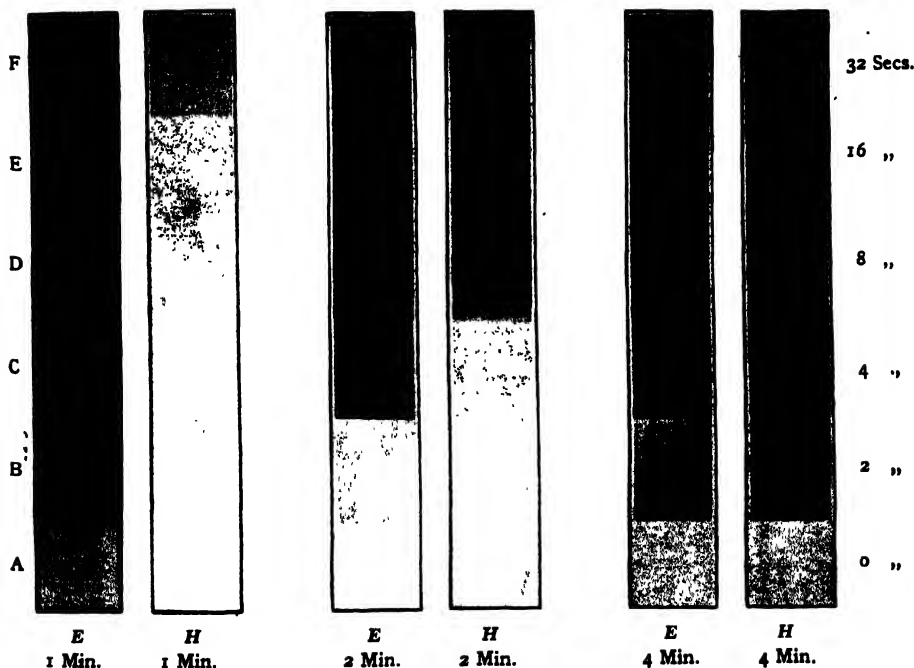


FIG. 28.13. COMPARATIVE EFFECTS OF METOL (E) AND HYDROQUINONE (H) DEVELOPERS

have received the same exposure; comparison is therefore difficult.

The test will be found of much more value if it is carried out on a scale of uniform tones obtained by exposing a plate or film in successive bands to intensities which correspond respectively to the shadows, half-tones and high-lights of average subjects; after cutting this negative into several identical strips, each comprising a complete scale of tones, strips are developed for different times in each of the two developers. After fixing and washing, corresponding tones are placed side by side for comparison. The following method was described by J. I. Crabtree, 1922.

Take a plate or film (preferably 7 x 5 in.)

front of the frame allows different times of exposure to be given to the various parts of the plate. At the start the card covers a band about half an inch wide and parallel to the longer side. This band will eventually be used for comparing the amount of chemical fog resulting from the various conditions of development. After two seconds' exposure, the card is pushed on about half an inch, and this is repeated after periods of 4, 8, 16, and 32 seconds, counting from the start of the first exposure. When this has been done, cut the plate or film into a certain number of pieces. Fig. 28.13. shows such pieces after different times of development in a metol developer *E* and in a hydroquinone developer *H*, and exhibits the characters of the two developers.

The image appears very quickly in the metol developer, whilst in the hydroquinone developer it appears very slowly, but the density then increases more quickly, so that the two negatives are almost identical after a sufficiently long time of development. Where many such tests are to be made, a negative should be made once and for all by the same method, and should be developed without being cut up. The darkest band should then be covered with black paper, and the time of exposure adjusted so as to produce, on development, only a faint density under the darkest of the bands next to the one covered by the mask.

442. The following method (Dundon, Brown, and Capstaff, 1930) is more particularly intended for the control of a tank in which the developer is replaced daily. For these experiments, small pieces of a slow film having a low tendency to fog, e.g. motion-picture positive film, should be used. The film is exposed always under identical conditions, behind a negative carrying several steps of uniform density, obtained as described above, but developed in a dilute bath to a low gamma value. In order to ensure that successive exposures are identical, they should be made in a printer having an automatic timing device and fitted with a lamp reserved for this purpose. To lengthen the life of the lamp it should be run at 10 to 20 volts below its normal rating, the current passing through the lamp being controlled by rheostat and an ammeter. A sufficient number of test strips are exposed at one time to serve the needs of about a week, the strips being used between the second and eighth day after exposure. During the period the change in the latent image is negligible.

Two strips are developed, one in the new bath and one in the old, both developers being at the same temperature. The tests can be carried out on samples of the solutions in glass cylinders of small capacity. The time of development from immersion in the developer to immersion in the stop-bath, is maintained constant and is chosen so that the least exposed step is barely visible on the strip developed in the new bath. Any differences between the stepped images will be readily apparent. The same degree of agitation should be given to both strips. When the strips are fixed and rinsed, they are compared side by side against an opal illuminator. If, each time a new bath is prepared, it is compared in this way with the old one, any mistake in the mixing will be revealed.

A very simple procedure has been described (W. F. Weiland, 1940) that is based on the fact that the time of appearance of a heavily exposed image on a gelatine-bromide paper, depends only on the degree of exhaustion of the developer. The relation between the time of appearance of the image on the test paper and the time of development for a given emulsion can be represented by a straight line.

443. The close control over the activity of the developer, which, since 1928, has been regarded as indispensable in motion picture processing where the tolerances in the gamma values are very small (± 0.05), is ensured by including a sensitometric strip between every five thousand feet of film.

In normal practice, it is not necessary to draw a complete characteristic curve for each strip, the gamma value being simply read off on a differential densitometer (L. A. Jones and M. E. Russell, 1935; E. Tausch, 1935); various other simple methods have been devised in order to measure the gamma by visual inspection (F. F. Renwick, 1914; J. Eggert, 1930) or by electronic means (H. Brandes and R. Schmidt, 1933). From time to time it is necessary to draw out a complete characteristic curve to determine the effective emulsion speed to find whether this is decreasing as the result of an abnormally high concentration of bromide in the bath.

In cinematography the gamma values are chosen so as to ensure the minimum distortion in the sound reproduction. Depending upon the particular recording system used, the gamma values (measured on a diffusing densitometer) lie between 0.55 and 0.80 for the negative and are about 2.0 for the print.

444. In establishments for the processing of amateur work, a gamma value of 0.7-0.8 is adopted for miniature films in order to avoid excessive graininess on enlargement. To achieve this end, it is necessary to give different times of development for films of different origin. The films are sorted into classes according to their rate of development. Stopping development at a low gamma value calls for perfect constancy of the reduction potential of the developer, and not only constancy in the time of development. It is essential, therefore, that the control of replenishment should be exact.

For the development of films of the usual size it is important that care should be taken to avoid a drop in the emulsion speed. Inquiries

by the manufacturers of sensitive materials have shown that this is not always done. Thus, it has been found that in one processing house the gamma values obtained on a succession of rolls from the same batch varied from 0.65 to 1.2, and, for the same gamma there was a range in emulsion speeds of 4 : 1, revealing an absence of proper replenishment (R. F. W. Selman, 1936).

Provided that correct replenishment is employed, or the time of development is appropriately varied, the variations in emulsion speed, as exhaustion proceeds, are negligible when the films are developed to $\gamma = 1.1$, but, on the other hand, they are considerable when development is stopped at $\gamma = 0.7$ (J. I. Crabtree, 1937). The characteristic curves in Fig. 28.14 and 28.15 correspond to sensitometric strips developed after exhaustion of the number of spools (of 8 exposures $2\frac{1}{4} \times 3\frac{1}{4}$ in.) per litre shown in the following table—

Curve No.	State of developer	Spools per litre	FIG. 28.14		FIG. 28.15	
			Dev. Time (min.)	γ	Dev. Time (min.)	γ
1	New	0	4	1.08	9	0.66
2	Replenished	105	4	1.15	9	0.93
3	Exhausted	26	18	1.12	40	0.93
4	Exhausted	26	9	0.66	9	0.66
5	Replenished	105	2	—	—	0.66

445. Interrupting the Course of Development.

At a time when only large-size negatives were

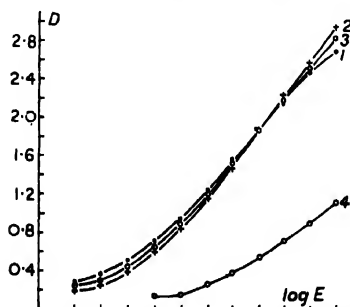


FIG. 28.14. THE EXHAUSTION AND REPLENISHMENT OF A DEVELOPER

used, on non-colour sensitive plates which would be considered slow to-day and which were developed by a bright safelight, it was the rule to study the appearance of the image, then its growth, and try to modify its characteristics in any desired direction. Development was started in a dilute bath having a low bromide

concentration. The time taken for the first details to appear and the delay between the appearance of the highlights and shadows would indicate to the photographer whether the exposure had been too great, correct, or insufficient, long before the image had attained the desired contrast. The plate was then placed in

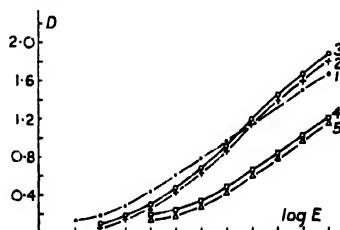


FIG. 28.15. THE EXHAUSTION AND REPLENISHMENT OF A DEVELOPER

a dish of water before transferring it to another dish containing another developer, better suited to its needs. A weakly alkaline, heavily bromided developer provided an ample regression of speed for an over-exposed image; an average developer was used for a normally exposed image, whereas a developer of very high reduction potential, without bromide and strongly alkaline, capable of developing out the weakest exposures, was used for an under-exposed plate. This method of *developing in several baths* was studied particularly by A. von Hübl (1897), director of the Austrian Geographical Service, who had to ensure the correct development of numerous negatives received from field expeditions whose personnel did not always enjoy a photographic competence equal to their skill in topographical matters.

It is sometimes incorrectly stated that changes in the composition of a developer can make no difference to the shape of the characteristic curve corresponding to a given gamma value. Some important variations can be obtained in the lower region of the curve by virtue of the fact that the development of all the grains does not set in at the same value of the difference between the potentials of the silver and of the developer (§ 374), and, as has already been mentioned, some changes (dilution of the developer, use of tanning developers, etc.), can change the shape of the upper region of the curve.

The amateur, to whom the small cost, represented by the quantity of developer, was negligible, and who often worked in a cramped space,

would prefer to modify by appropriate additions the developer in use, momentarily transferring it to a glass tumbler.

Frequently the photographer developed his own plates. He knew the characteristics of his subject and would use from the start a developer suited to the range between the extreme brightnesses of his subject in order to obtain a superficial image of low contrast or a deeply developed image of high contrast (§ 391). According to the circumstances, he shortened or lengthened the development, attempting (without always succeeding, because visual judgment is very uncertain in this matter) to reach an optimum density range in the negative, a necessary condition for the production of perfect prints on the limited number of types of paper at his disposal; papers which scarcely differed, one from another, in speed or whose contrast only varied within close limits.

While some adroit workers, possessed of much leisure, obtained remarkable results in this way and found pleasure in thus wrestling with the problem, the tyro or occasional photographer worked sometimes in the wrong direction as a result of frequently confusing the notions of density and contrast.

446. Such methods of working, obviously, could not be applied to miniature negatives where the details are too small to be studied by safe-light and which would no longer be manageable after cutting up the film into individual images. This applies especially to fast panchromatic films developed in almost total darkness. The great exposure latitude in modern negative films and the great variety of papers that are available, can accommodate a wide range of density differences and make the individual control of each negative often unnecessary. Moreover there are not many, even among the most enthusiastic amateurs, who can spare the time.

In the motion-picture industry the working volume of developer in a laboratory is always several thousand litres, a fact which makes it impossible to modify the developer formula. It is difficult even to give a different time of development for each scene and, moreover, there is only one type of positive film available. The results obtained under these circumstances show that very satisfactory, if not always perfect, negatives can be obtained without any visual control over development.

It should be noted that the procedures which will be described below, using in succession two developers of more or less different composition,

are intended to reduce the consumption of developing solutions when developing to a constant gamma, and are not intended for the control of negatives, neither individually, nor in groups.

447. **Factors Influencing the Time of Development.** Under any given circumstances (of subject, type of emulsion, composition and temperature of developer), where the exposure has been ample, there is no *one* optimum developing time, but a more or less extended range of times. The particular time chosen would depend on the contrast grade of the paper that is to be used for printing the negative. The shorter times yield negatives of lower granularity and are to be preferred for negatives intended for enlargement and for negatives that need retouching.

When it is desired to bring out the shadow details in an under-exposed image, there is, in general, an optimum time of development (or, to be more precise, an optimum value of gamma) beyond which the shadow details become more and more lost in the background fog (E. R. Bullock, 1926). When the developer has an appreciable induction period (developing agent of low reduction potential, or a partly exhausted, or heavily bromided solution), this optimum time of development often leads to an excessive contrast in the negative (S. O. Rawling, 1932) which necessitates subsequent treatment. In the case of certain emulsions, where the characteristic curve has a long, curved toe, and where a high gamma value can be reached in a non-bromided, high-potential developer, without the appearance of appreciable fog, it is possible to compensate for much under-exposure in the case of low-contrast subjects (when all the exposures are situated on the toe of the curve) by considerably prolonging development (F. F. Renwick, 1913; R. Luther, 1923).

As a result of this characteristic, it is sometimes possible to obtain better images of fast-moving objects on material of average speed than on ultra-rapid emulsions. The density range is not always large enough for the negatives to be used directly, but they give satisfactory prints after *proportional intensification* (§ 540).

448. The time of development that must be given to obtain a desired gamma value depends upon—

1. The type of emulsion used. The times of development needed to reach a given gamma value can vary as much as 8 : 1 on passing from

one negative emulsion to another, and 2 : 1 among successive batches of the same brand.

The more rapid emulsions, having larger grains, develop more slowly than the slow, fine-grain emulsions. Film-pack films, protected from abrasion by a thin layer of gelatine that slows down the diffusion processes, require a somewhat longer time of development than another film employing the same emulsion but without the super-coat.

2. The composition, the concentration, and the temperature of the developer and on the agitation. The influence of all these circumstances on the time of development has been studied. Except in an industrial establishment where the concentration of useful product in each of the constituents of the developer can be found by analysis, the composition of the developer can vary, unknown to the operator, each time a new batch of a chemical is used.

In order to develop to a given gamma value, when the developer is always used fresh (in some scientific applications) or at constant activity, it is necessary to prepare a curve showing the gamma value for each time of development, the developer being at constant temperature. If the temperature cannot be maintained constant, the temperature coefficient for the developer and the emulsion should be known. When the developer is not constantly replenished, it is necessary to draw the curve showing the time of development as a function of the area of the material previously developed in a given volume of developer.

449. Judging the End of Development. The term "visual control of development" implies that development can be stopped at the moment when the density range reaches the optimum for the particular photograph. Unfortunately, there is no means of achieving this condition; the estimation of the density range by inspection, without photometric measurements that are almost impossible during development, results in gross errors, except after long practice on a particular type of work. The coloured light, on the one hand, and the presence in the emulsion of the silver bromide, constituting a weak positive image complementary to the negative image, on the other hand, affect the apparent contrast in opposite ways without compensating each other. Moreover, it is difficult to avoid the mistakes of over-estimating the density range on a negative of low average density, and under-estimating the density range

on a negative of high average density. Some professional portrait photographers use a negative comparator, an opal illuminator in front of which are fixed two negatives, suited, respectively, for printing on the most soft, and most contrasty printing papers used in the studio. A space is left between the two negatives to take a negative for comparison. The opal is illuminated with white light for the examination of fixed negatives, and by orange or green light for unfixed negatives, in which case the standard negatives should be stabilized by iodization rather than by fixing.

Various methods have been recommended to beginners to enable them to stop development at a time that is neither too early nor too late, without, however, there being any foundation of facts between the standards of judgment and the desired results.

In particular, it has been suggested that development should be stopped when fog appears on the parts of the negatives that were protected from exposure (by the rebates of the plate-holders, or the back frame of the camera), or at the moment when the dense parts of the image can be seen through the back of the plate or film. This latter recommendation is useless, however, when there is more than one coat of emulsion and, also, when the material carries an antihalation layer of the type that does not disperse in the developer.

The time of appearance of one or other of these two conditions can be influenced by many factors not connected with the rate of development of the image, such as accidental light fogging when loading or in the early stages of development, a poor developer which may also be dilute or too warm, an emulsion more or less rich in silver bromide. Thus, such recommendations are only of a makeshift nature.

When negatives are examined by transmitted light during development, plates should be held by their edges and cut films by the corners, if they are not in holders. The negative should not be held closer to the safelight than is necessary, especially if the safelight is warm. Prolonged examination should be avoided, especially at the commencement of development of non-desensitized materials.

450. When a normally exposed negative has been developed to a given gamma value, the difference between the extreme densities depends mainly on the ratio between the extreme brightnesses of the subject, and the maximum density upon the degree of exposure. In order

to keep the density range constant, the time of development should be varied inversely as the ratio of the extreme brightnesses of the subject. Otherwise, the most regular results are obtained by developing to a constant gamma value. If the gamma value is chosen so as to allow negatives, normally exposed on subjects of a brightness range of 30 : 1, to be printed on normal grade paper (this would be $\gamma = 1.1$ for constant printing), then negatives of very contrasty subjects can be printed on soft paper, and negatives of low-contrast subjects can be printed on contrasty paper. Thus, in summer, a greater proportion of soft paper would be used than in winter. The deviations involved in visually judging the end of development would be greater than those found in working to a constant gamma.

It should be recalled that it is possible to develop non-colour-sensitized emulsions to an almost constant gamma value by using a time of development that is a suitable multiple of the time of appearance of the image (§ 381).

Some manufacturers of sensitized materials indicate, for their products, the times of development which will give suitable gamma values (0.8–1.00–1.25) when the recommended developers are used at the stated temperatures. Other manufacturers publish, for some recommended developers, the curves showing the gamma values as a function of the time of development at an average temperature, and the graphs indicating the equivalent times of development at various temperatures. It would be a good thing if the provision of such information were more general. However, it should be added that such publications imply a constancy of the properties of the materials that is not always found in the various batches of a particular brand. In fact, the variations are sometimes such that on developing a large number of batches of the same brand to obtain an average value of 1.0, the values obtained range from 0.7 to 1.3.

451. Rinsing after Development ; Stop-baths ; Provisional Fixing. The developed negative should be rapidly transferred into a tank or a dish of water, or placed under a jet of water, of moderate pressure, in order to remove the surplus developer and, as much as possible, the developer that is in the emulsion and the gelatine backing layer. In this way one avoids carrying into the fixing bath an appreciable quantity of developer which, on accumulating, can cause spots, dichroic fog, or the precipitation

of the alum often employed in fixers in order to harden the gelatine. The hardening property of the fixer reduces the amount of water absorbed in washing and thus increases the rate of drying.

Since development can continue while the negative is being rinsed in water, often causing local irregularities, it is preferable to use as a *stop-bath* a very dilute solution of an acid, or of an acid hardening agent, that stops development rapidly by neutralizing the alkali. The stop-bath can be acidified by adding 2 per cent sodium bisulphite, 2 per cent boric acid, or 2 per cent acetic acid. The stop-bath should be checked from time to time with litmus paper to ensure that it is still acid.

452. The use of a chrome-alum hardening stop-bath has the advantage that the hardening obtained is more complete than can be obtained by adding potash alum to the fixing bath. The fixer is then more stable and the recovery of silver is made easier.

Chrome-alum, or potassium chromium sulphate, $K_2SO_4 \cdot Cr_2(SO_4)_3 \cdot 24H_2O$, molecular weight = 999, appears usually as large, deep-violet crystals of good purity. The solutions prepared in the cold are grey-violet in colour and become green on warming to 60°C, under which conditions the hardening, or tanning properties are diminished, while the acidity is increased. The salt is quite soluble in water (20 per cent at 15°C). The hardening properties of the solution are rapidly impaired on adding sulphite or bisulphite, or organic acids such as citric, tartaric, and oxalic acids. It is not affected by acetic acid.

The best results are obtained in a 3 per cent solution of chrome alum at $pH = 3.2$. The developer carried over into the stop-bath by the developed plates, etc., rapidly diminishes the efficiency of the stop-bath and this is shown by a change of tint from violet to yellow-green. To prevent this change the bath should be periodically re-acidified by small additions of dilute sulphuric acid. The acidity of the stop-bath is best controlled with the acid of brom-phenol blue indicator.

To carry out the test 0.4 g of the bromphenol blue dye is dissolved in 75 ml of a 0.05 per cent solution of sodium hydroxide and the solution is made up to one litre with distilled water. About 2 ml of the stop-bath are diluted by adding 5 ml of distilled water and six drops of the indicator solution. By daylight the resulting colour should be reddish-yellow.

After the negatives are immersed in the stop-bath they should be agitated for not less than 45 seconds to avoid the appearance of blisters, or spots, or the formation of chromium hydroxide in the emulsion layer. The negatives should remain in the stop-bath for about 3 minutes.

When a hardening stop-bath is used, it is essential, after the final washing, to dry carefully the gelatine surfaces to which traces of chromium hydroxide will finally be found to adhere.

The use of a hardening stop-bath is particularly to be recommended when the temperature of the processing solutions is in excess of 25°C. When working at 30°C, after developing in a bath loaded with sodium sulphate (§ 435), a stop-bath of 3 per cent chrome-alum loaded with 10 to 15 per cent of sodium sulphate should be used.

When the volume of work is large, the re-acidifications of the stop-bath can, after preliminary trials, be based on the area of the gelatine surfaces that have passed through the bath.

453. When working under difficult field conditions where washing after fixing would be difficult, proper fixing can be postponed, and *provisional fixing* employed. This consists of an acid stop-bath followed by a brief rinse. A weak acid such as boric (5 per cent solution) is to be preferred, because a strong, non-volatile acid will, on keeping, break down the gelatine if it has not been removed. Drying should be carried out away from a bright light.

To enable the negative to be examined in white light as rapidly as possible after development, it can be iodized by bathing for 2 minutes in the following bath (J. G. Capstaff, M. L. Dundon, and G. H. Brown, 1930).

Potassium iodide	20 g
Glacial acetic acid	20 ml
Potassium alum	40 g
Sodium sulphite, anhydrous	1 g
Water to make	1 litre

After iodizing, the negative should be rinsed in several changes of water, the last containing a little ammonium hydroxide. If it is desired, ultimately, to fix an iodized negative, a new fixing bath or a special fixer (§ 502), should be used, because the silver iodide is less readily soluble than the bromide.

454. **Critical Examination of Finished Negatives.** Although negatives cannot be usefully examined until after they are fixed, and preferably after they are washed and dried, it does not

seem proper to postpone to a later chapter a matter which is so intimately connected with the question of development.

The examination of a negative that does not carry high densities is best made by placing the negative, emulsion side down, on a mat white surface and viewing it by reflected light. A very dense negative is more easily inspected by transmission against an illuminated opal glass, or, failing an opal, a ground-glass, or a sheet of tracing-paper.

In an industrial or scientific establishment, a negative viewer should be used of the type usually used for radiographs which can hold wet or dry films, by means of clips, against a vertical opal glass that forms the front face of a lantern.

Mention may be made here of a photo-electric apparatus that shows an enlarged positive image of a negative on a phosphorescent screen (F. Biedermann, 1937). This arrangement is chiefly designed for dealers to interest their customers in purchasing enlarged prints of their negatives.

455. Before making final judgment, account should be taken of the fact that details, particularly in the shadows, that are not clear on the negative may appear in prints made on very contrasty paper (L. A. Jones, 1939). Such a negative is thus very acceptable if the difference between the extreme densities does not exceed the value that can be tolerated when printing on papers of this sort. This does not apply, of course, to negatives that are to be studied without printing or on which it is intended to make measurements (in radiography, photogrammetry, spectrography, etc.), but, if the shadow details would appear in a print, they could be made visible on the negative by strong intensification.

A relatively high density of the image of the shadows (0.5 for example) should not be confused with fog. The fog density will be shown on the parts of the negative that were protected from the action of light in the camera.

A negative is not under-exposed provided that the density in the image of the darkest shadow, in which it is desired to discern details, is very slightly greater than the fog density.

A negative that is well or over-exposed often shows a weak positive image when examined by reflection on the support side, the light falling obliquely on the negative which is held before a dark background. Under the same conditions, a less exposed, or under-exposed negative sometimes shows a positive image when the emulsion

side is examined. A normally exposed negative can thus show a positive image on inspecting both sides. These characteristics are not invariable, however.

A negative is not over-exposed provided that when properly printed the image of the highlights is sufficiently detailed. When the range between the extreme brightnesses of the original subject is very extended, the negative may be under-exposed with regard to the image of the shadows and over-exposed with regard to the image of the highlights. A better result would probably be obtained on a negative material able to record a wider brightness range.

If the negative shows details in the shadows and in the highlights, but, as a result of being developed to too high a gamma, the range between the extreme densities is too great to allow printing on the softest paper, and if the negative is sufficiently valuable to justify the trouble, it can be reduced (§ 562), or it can be dealt with by the procedure that allows the compression of the middle tones (§ 648), though these operations are rather delicate.

A systematic under-exposure may be the result of over-estimating the speed of the films or plates, or of the exposure meter being out of order or used under the wrong conditions, or it may result from the scale of the diaphragm apertures being in error. A systematic over-exposure may be due, among other causes, to an error in the calibration of the shutter.

456. Photographic beginners, and some experienced workers, easily confuse the notions of density and contrast. Just as it is possible to meet a very steep path at a low altitude and a gentle incline on a high mountain, a negative can be at one and the same time very clear (very low density in the shadows) and very vigorous (great density range), or very dense (relatively high density in the shadows) and very flat (small density range). Thus, there is no correlation between the average density of a negative and the range between the extreme densities.

It is essential to take account of the fact (except when considering granularity) that the characteristics of the image depend only on the range between the extreme densities, the density of the shadow details affecting only the time of exposure when printing. If two similar negatives, made on similar materials, similarly developed, have been exposed under conditions such that corresponding densities differ by one unit (all the opacities of one negative being ten times those of the other), the contact prints

obtained on the same paper, using times of exposure in the ratio 10 : 1, would be identical.

The photographic vocabulary is somewhat confusing in regard to negative characteristics, the same term being sometimes used with very different meanings. In the following pages the arbitrary terms shown in the following table will be used. But a negative can only be usefully defined by stating the gamma to which it has been developed and the range between the extreme densities.

Classification of negatives		
According to the density of the shadows	According to the range between the extreme densities	According to the gamma value
Very low—clear	Low—flat	$\gamma < 1$ (contrast low) soft
	Medium—medium contrast	$\gamma = 1$ normal contrast
Great—dense	Great—vigorous	$\gamma > 1$ (contrast high) hard

457. The rock on which the beginner usually comes to grief is his ignorance of the characters that a negative should possess in order to yield good prints by the usual printing processes. The rational apprenticeship of the photographer should, in our opinion, begin by printing from negatives of suitable quality. For instance, two negatives may be used, one suitable for print-out paper or rapid bromide paper of weak contrast, and the other for a paper of very great contrasts, which negatives must, of course, be supplied with advice as to their correct use. Having acquired experience in printing, the beginner will be in a position to judge what results to expect from his negatives, whereas for lack of a guide, it is usually impossible for him to distinguish between faults in the negative and errors in printing.

WORKING PROCEDURE

458. Preliminaries. Before beginning the development of a negative it is necessary to see that all solutions and equipment are at hand. The tanks or dishes should be so arranged that the negative being developed may be transferred from one to another in proper sequence. They should be filled with the various baths required, taking care that the temperature of these solutions is about the same as that of the darkroom, which should whenever possible be between 65°F and 70°F. The dishes containing the fixing bath should be placed so that no splashes can reach the developer.

When the various baths, and particularly the developer, are prepared at the time of use by mixture or dilution of stock solutions, the water used for dilution should have been kept for a while in the darkroom in order to acquire its temperature. In all cases be careful not to dilute with water straight from the tap. The tap water is usually colder than the developing solution, and it also contains air which separates in bubbles when the mixture becomes warm; these bubbles may adhere to the gelatine of the negatives, preventing the developer from acting at these points.

To ensure the perfect uniformity of a mixture it is necessary to stir vigorously. On no account should the various liquids to be mixed be poured separately into a shallow dish, where it is very difficult to obtain a uniform solution even after prolonged agitation. It is still more important to avoid a direct addition to the bath during development of negatives. When developing in a dish, the developers must be poured back into the graduate, and any required additions then made. When developing in a tank, the negatives must be removed, and the developer stirred energetically after adding the new solutions.

It is essential that every care be taken to ensure uniformity of treatment during the various manipulations. For this, the emulsion must be wetted almost simultaneously at all points by a perfectly uniform developer, and the plates or films must then be moved several times.

It is specially essential that the solutions used should be perfectly clear, as any suspended matter produces a spot where it settles on the emulsion. All stock solutions and baths previously in use should therefore be poured off from any sediment.

With prolonged use, a sludge of reduced silver and calcium sulphite forms in a tank of developer and, overnight, this settles on the bottom of the tank. However, the sludge is stirred up when the bath is next used and there is a danger of it adhering to the emulsion surfaces. Such a deposit can be easily removed before recommencing work, and without agitating the bulk of the liquid, by use of the following device (C. E. Ives, A. J. Miller, and J. I. Crabtree, 1931). A steel tube, about 3 mm ($\frac{1}{8}$ in.) internal diameter and somewhat longer than the depth of the tank, terminates in a long narrow nozzle, similar to that used on vacuum cleaners. The steel tube is connected by thick-walled rubber tubing to one of two tubes passing through the stopper of a thick-walled glass bottle or demijohn capable

of holding about 1/30 of the contents of the tank. The other tube in the stopper is connected by another length of the rubber pressure tubing to a filter pump. By passing the nozzle gently over the bottom of the tank the lower layers of developer containing the sediment are drawn off into the bottle. After the sediment has settled in the bottle the developer is decanted and the sediment is added to the other silver residues for recovery of the silver metal.

The surface of a used bath is often contaminated by a film of scum which will adhere to the emulsion as it is lowered into the solution, and will cause local undeveloped patches. This scum will not adhere if the surface is previously wetted, but it is better to skim the surface of the developer with a piece of filter paper, or butter muslin on a frame, immersed obliquely to a depth of half an inch. This operation should precede the dredging of sediment.

Intense fog has been noticed on non-colour-sensitive materials which had been developed, by the light of an appropriate safelight, in a developer that had been previously used for developing colour-sensitized materials (O. Bloch, 1915).

459. Wetting Plates and Films before Development. In quantity work the adherence of air-bubbles to the gelatine is sometimes avoided by wetting in water containing a little alcohol (industrial spirit). Nowadays it is more usual to use very dilute solutions of the wetting agents used in textile manufacture: saponine, sulphorincinates, and sulphonated fatty alcohols (Ocenol, Lorol, Igepon, Teepol, etc.). These substances can also be added to the developer (§ 417) or to the desensitizing bath (§ 365).

Preliminary wetting accelerates development in a concentrated developer and slows it in a dilute one. With some developers it is possible to ascertain by methodical tests the strength required in order that the duration of development should not be affected by the preliminary wetting. Any tanning of the gelatine reduces the speed of development only very slightly.

In every instance where the emulsion has been wetted before development it is necessary to rock the developing dish energetically for a few moments or to move the plate-holders or film-hangers in the solution so as to ensure the uniform replacement of the water or solution impregnating the gelatine by the developer.

460. Hardening the Emulsion before Development in Warm Solutions. Under tropical, or other warm conditions, the hardening of the

gelatine can be deferred until after the development by making suitable additions to the developer (§ 417) but this method of working is only applicable at solution temperatures up to 35°C (95°F), and even at 30°C (86°F) there is some degree of risk.

The usual developers can be used up to 40°C (104°F) if the negative is hardened in a pre-bath according to the technique described below (H. A. Miller, J. I. Crabtree, and H. D. Russell, 1944).

Various attempts had previously been made to harden the gelatine in formalin (§ 519), but the formalin retained in the emulsion often caused the appearance of an intense fog on the developed images. All risk of fog is avoided by the addition of an antifogging agent to the hardening bath (§ 386).

The bath is prepared immediately before use by mixing the two stock solutions. At temperatures above 35°C (95°F) the quantity of antifogging agent is increased up to double, if necessary. The bath will keep for about three weeks at a temperature of 35°C. The negatives are immersed for an average time of 10 minutes, after which they are drained and rinsed and then placed in the developer. About five square feet (50 square decimeters) of film can be treated per litre of bath. In an industrial establishment, the bath can be maintained at constant activity by adding a replenisher solution to top up the bath to a constant level. In this way 30 to 40 square feet (300 to 400 square decimetres) of film can be treated per litre of the initial bath.

		Normal bath	Replenisher
		1 litre	1 litre
(A)	Water to make 6-nitrobenzimidazole nitrate (0.5 per cent solution)	40 ml	55 ml
	Sodium sulphate, anhydrous	50 g	50 g
	Sodium carbonate, anhydrous	10 g	23 g
(B)	Formalin (commercial strength)	5 ml	8.5 ml

Pour B into A, while stirring. Final pH = 10.1.

461. Air Bubbles. A small amount of air is sometimes drawn into the solution when the mat surface of the emulsion is plunged into the bath, and this air tends to form adherent, hemispherical air-bubbles, or air-bells. The hemispherical bubbles tend to become spherical, reducing the area in contact with the emulsion. Thus, when air-bells are formed in the developer, the non-developed zone is surrounded by a degraded border. The bubble tends to lengthen in a vertical direction, the tendency being greater the larger the bubble. In a developer that tends to give aerial fog (§ 337), the circumference of the non-developed zone is often more dense, and there is often a descending, denser streamer

below the bubble (J. I. Crabtree and C. E. Ives, 1926).

If a gelatine layer is immersed in water or in an aqueous solution and is removed before it is completely swollen, a large number of air-bells tend to adhere on reintroducing the partly swollen gelatine into the liquid.

462. Immersion in the Developing Bath. When developing a plate in a dish, hold it by its edges, emulsion upwards. Large plates must be supported on the four spread fingers of the right hand and held by the thumb placed on the extreme edge. For very large plates the help of an assistant is almost indispensable. The dish is tilted to collect all the developer along one side. An edge of the plate is then rested on the edge of the dish opposite to the one where the developer is lying. The dish is then let down into the horizontal position, and, at the same time, the plate is lowered to the bottom of the dish. The plate is thus swept almost instantaneously by the liquid. The dish is gently rocked, and care is taken to see that the plate is uniformly wetted. Unless the worker is skilled, it is best to avoid developing several plates together in one dish, as there is a risk of damage from one plate sliding over another. However, it is possible to obtain dishes with low dividing ridges on the bottom for the simultaneous development of several stereoscopic plates, and separators of moulded material permitting several plates of small size to be developed together in an ordinary dish.

About 100 ml of developer is required in a dish of half-plate ($6\frac{1}{2} \times 4\frac{1}{2}$ in.) size, and proportionate quantities in dishes of other sizes. It may be well for a beginner to increase these amounts by one-third in order to avoid any irregularity in the wetting of the emulsion by the developer.

When developing cut films in a dish it is best to choose a dish sufficiently large to accommodate two films side by side, and to have plenty of developer in order that the films be well covered in spite of their tendency to curl. The film is slid into the developer, emulsion upwards, and, while held by two adjoining corners, is drawn to the half of the dish farthest from the operator. As soon as this film is well wetted with developer several other films may be introduced in succession, each being drawn to the back of the dish, leaving the front half free, until the last film of the batch has been introduced. The films become very soft, and must be handled with care. They are taken

one by one and transferred in reverse order to the front half of the dish, and this transfer from one pile to the other is continued until development is completed.

When single frames or hangers are used with plates or films developed in a tank, care must be taken to see that air-bubbles are not imprisoned in the frame, as such bubbles, when rising, may adhere to the emulsion. To do this, the frames are immersed one corner first, obliquely, and they are gently moved up and down immediately after immersion. The plates or films are introduced with the emulsion facing the operator, and are put in at the back of the tank and then brought to the front so as to leave the back free for the others. By proceeding in this way there is no danger of scratching the emulsion of one negative by the frame containing the next.

After inserting the last frame, the frames are separated as far as possible and moved up and down singly from time to time in order to bring fresh solution in contact with the emulsion. In doing this, each frame must be drawn away from the one behind it so as to avoid scratching the gelatine of the latter.

If the frames are much narrower than the tank they all must be pushed up against one side to avoid retarded development of such parts of the emulsion of a plate or film as would come too close to the vertical side of another frame. Unless the frames are very widely separated from each other it is necessary to avoid developing together negatives of different sizes.

When development is done in vertical, grooved troughs, the developer should be emptied from time to time into a jug, from which it is at once poured back into the tank. Instead, the tank, if fitted with a watertight lid, may be reversed every two minutes.

Owing to the variety of the tanks intended for the development of roll-film, the only reference which can be made is that the instructions issued with them should be followed.

DEVELOPER FORMULAE

463. Developers for Negative Materials of Large and Medium Sizes. The few formulae collected below correspond to developers that will yield high gamma values, suitable for the development of negatives that are not intended for enlarging more than five diameters and when great attention need not be paid to the question of graininess.

First will be given the developers more

particularly intended for use in dishes (although many of them can be used in tanks for the development of a limited number of negatives). Then the formulae for large-scale development in deep tanks, with replenishment, will be given.

The times of development quoted are only approximate, but will probably yield a satisfactory negative.

Fine-grain developers, successive-bath developers, tropical developers, ultra-rapid developers, and developer-fixers are dealt with later.

464. Pyrogallol Developer. This developer (*British Journal Almanac formula*) by C. W. Piper, is one of the best known using pyrogallol. The stock solutions are stable and the images are not stained.

(A) Sodium sulphite, anhydrous	75 g
Potassium metabisulphite	18 g
Pyrogallol	18 g
Water to make	1 litre
(B) Sodium carbonate, anhydrous	55 g
Water to make	1 litre

For soft negatives, 1 volume of A and 1 volume of B should be mixed with 2 volumes of water immediately before use. Develop for 4 minutes at 18°C (65°F). For vigorous negatives, use 1 volume A, 1 volume B, and 1 volume of water. Develop 5 to 6 minutes at 18°C (65°F).

465. Metol Developers. When making up developers containing metol, a pinch of sulphite should be dissolved first. After dissolving the metol, add about half the quantity of sulphite and add the remainder of the sulphite after the alkali has been added. The poor solubility of metol base, liberated by the sulphite, tends to cause its precipitation and it is difficult to redissolve. In metol-hydroquinone developers, there is a danger, under similar conditions, of precipitating metoquinone. The precipitation becomes more likely, until the alkali has been added, as the concentration of sulphite is increased.

The following developer (Reinders and Beukers, 1931) is only slightly susceptible to small variations in pH. Its usual pH value is 9.0.

Metol	9 g
Sodium sulphite, anhydrous	20 g
Borax	20 g
Sodium carbonate, anhydrous	5.5 g
Potassium bromide	0.5 g
Water to make	1 litre

The following developer was used in the photographic sections of the French Air Force.

Metol	7.5 g
Sodium sulphite, anhydrous	37.5 g
Sodium carbonate, anhydrous	17.5 g
Water to make	1 litre

466. Metol-hydroquinone Developers. The following developer, recommended for amateurs by the French Photographic Manufacturers' Association, can be used for negatives, black-and-white transparencies, and bromide and chloride papers. It is the average of a number of only slightly varying formulae that were previously recommended for the various purposes.

Metol	2 g
Sodium sulphite, anhydrous	35 g
Hydroquinone	5 g
Sodium carbonate, anhydrous	25 g
Potassium bromide	1 g
Water to make	1 litre

The following formula (J. I. Crabtree, 1921) is recommended for the development of *badly under-exposed* negatives. The developer, pH value 10.3, which is used without dilution has only a very limited keeping life (a few days in a well-stoppered bottle). The normal time of development is about 8 minutes at 18°C (65°F).

Metol	15 g
Sodium sulphite, anhydrous	50 g
Hydroquinone	15 g
Sodium hydroxide	8 g
Potassium bromide	8 g
Alcohol (industrial spirit)	50 ml
Warm water to make	1 litre

467. Paraminophenol Developers. The following developer (S. E. Sheppard and A. P. H. Trivelli, 1928) was recommended by the International Congress of Photography as the *standard sensitometric developer*, and for use in photometric photography (in which case 0.04 g of 6-nitrobenzimidazole nitrate should be added per litre). This developer is very easily made, and gives consistent solutions. Its pH, which is very stable, has an average value of 10.15.

Sodium sulphite, anhydrous	50 g
Paraminophenol hydrochloride	7.3 g
Sodium carbonate, anhydrous, pure	50 g
Water to make	1 litre

The time of development is usually between 8 and 15 minutes at 18°C (65°F).

Very concentrated solutions that yield developers on diluting 20 times (i.e. 1 part stock solution with 19 parts of water) are commercially available under various trade names, Rodinal, Azol, Kodinol, etc. One such developer can be prepared in the following manner (J. Desalme, 1913). Dissolve 75 g of paraminophenol hydrochloride in 600 to 700 ml of warm water. Filter if necessary. Add 10 g of

anhydrous sodium sulphite and 35 g of anhydrous sodium carbonate, previously dissolved in 200 ml of warm water. The free base is precipitated and, after cooling, it is filtered off on fine cloth. The paste of the precipitated free base, which should be drained until it occupies no more than 300 ml, is added to 100 ml of a 460 g per litre solution of sodium hydroxide. It should be added gradually until the precipitate just redissolves, avoiding an excess. Make up to 500 ml by adding water. Filter and store in small bottles, closed with rubber stoppers.

468. Glycin Developer. The following developer (Glyconol, H. Bourée, 1922) is given at working strength for use in a dish. A stock solution of five times the strength may be made for use at a dilution of one part with four parts of water. The time of development is 8 to 10 minutes at 16°C (61°F). At a greater dilution it is suitable for use in tanks with a developing time of 20 to 30 minutes.

Sodium sulphite, anhydrous	15 g
Potassium carbonate	30 g
Sodium carbonate, anhydrous	20 g
Glycin	10 g
Sodium bisulphite	2 g
Water to make	1 litre

469. Amidol Developers. The following developer which is well suited to somewhat under-exposed negatives, has the advantage of being simple to prepare immediately before use. As it does not keep, it should be used at once. The time of development is about 4 minutes at 18°C (65°F).

Sodium sulphite, anhydrous	3 g
Amidol	0.5 g
Water to make	100 ml

This developer is useful when travelling. Quantities of sulphite can be put up in small packets or tubes before starting, and a salt-spoon filled level with amidol is a sufficiently close approximation to 0.5 g.

For over-exposed negatives, a depth developer (§ 390) can be used, with a time of development from 2 to 12 hours. The developer is slower when the neutral sulphite concentration is smaller—

Amidol	10 g
Sodium bisulphite	15 g
Sodium sulphite, anhydrous	6 to 8 g
Water to make	1 litre

470. Paraphenylenediamine Developer. This developer (J. Desalme, 1911) keeps very well,

but if it is to be kept for long periods the sodium hydroxide should not be added until the developer is required for use.

Paraphenylenediamine (free base) . . .	10 g	—
Paraphenylenediamine (hydrochloride) . . .	—	17 g
Sodium bisulphite	12.5 g	12.5 g
Sodium hydroxide	20 g	24 g
Potassium bromide	3 g	3 g
Water to make	1 litre	1 litre

471. High-contrast Developers for Reproduction Work. The following developer is prepared at the moment of use by mixing equal volumes of the stock solutions. The developer ($pH = 12.5$) develops to maximum contrast in about 3 minutes. It darkens very quickly and should be used once only.

(A) Sodium bisulphite	23 g
Hydroquinone	25 g
Potassium bromide	25 g
Water to make	1 litre
(B) Sodium hydroxide	40 g
Water to make	1 litre

This developer is very caustic and tends to break down the gelatine when the temperature exceeds $20^{\circ}C$ ($68^{\circ}F$). The following developer, which keeps better, is often used instead and it may be used in a tank for the development of a large number of negatives. The time of development in the fresh bath is about 5 minutes at $18^{\circ}C$ ($65^{\circ}F$).

Metol	1 g
Sodium sulphite, anhydrous	75 g
Hydroquinone	9 g
Sodium carbonate, anhydrous	25 g
Potassium bromide	5 g
Water to make	1 litre

A developer giving infectious development (§ 398) is sometimes used for line, and coarse half-tone dot images. In this developer (Kodak D85), most of the sulphite combines with the formalin resulting from the depolymerization of the trioxymethylene, and the effective sulphite concentration is maintained at a low level

Sodium sulphite, anhydrous	30.0 g
Trioxymethylene	7.5 g
Hydroquinone	22.5 g
Potassium metabisulphite	2.5 g
Boric acid	7.5 g
Potassium bromide	1.5 g
Water to make	1 litre

472. Roll-film Developer. The following developer (Ilford Laboratories, 1935) is suitable for the development of roll-films of average

size in tanks or on continuous machines. The bath is maintained at constant volume by adding the replenisher solution.

	Developer	Replenisher
Metol	6 g	15 g
Sodium sulphite, anhydrous	100 g	200 g
Sodium bisulphite	25 g	25 g
Hydroquinone	30 g	15 g
Sodium carbonate, anhydrous	90 g	180 g
Potassium bromide	3 g	—
Water to make	10 litres	10 litres

473. Fine-grain Developers. Many poorly qualified experimenters have published observations on fine-grain development that are very erroneous and often contradictory. The comparisons of the granularity of negatives developed in different developers have no significance unless they refer to equal densities on negatives that were exposed under identical conditions and then developed to the same gamma value. It has already been mentioned (§ 211) that, in fact, the granularity of a negative varies from one part to another as a function of the density, and from one negative to another (similarly exposed on the same material) as a function of the gamma value. These variations can be easily explained by the fact that the development of different grains sets in after a delay that depends, among other factors, on the degree of exposure, and that the development is not complete at the instant that it is stopped. The necessity of comparing negatives exposed under identical conditions (without the danger of errors caused by capricious shutters) results from the fact that, on the one hand, all developers do not give the same emulsion speed at equal gamma values, and, on the other, that the speed is generally greater when development is carried to a higher gamma value. If development is curtailed to reduce the granularity, it is necessary to increase the exposure, and it is obviously desirable to know what sacrifice in speed must be made.

474. The fine-grain developers are, in fact, those slow developers in which the development can be stopped at a gamma value between 0.6 and 0.8, thus making only partial use of the speed of the emulsion. Since the diminished granularity results from the fact that only a fraction of each grain is reduced, it is necessary to increase the exposure so as to affect a larger number of grains (W. Reinders and M. C. F. Beukers, 1938). The best fine-grain developer is that which, for the same low value of gamma, occasions the least increase in exposure. Obviously, to avoid as much as possible the loss in

speed, the addition of soluble bromide must be avoided, an addition which, moreover, is pointless because of the low activity of these developers (G. Schwarz, 1935). The best known fine-grain developers require double the exposure that would be needed in the case of the majority of developers for large and average-sized negatives. Some of the developers that have been suggested for miniature negatives require six times the normal exposure, an increase that is inadmissible unless this disadvantage is offset by a great reduction in granularity.

475. The fine-grain developers are all slow-acting, in order to avoid the irregularities that result when development in an energetic developer is stopped at a low gamma value. Rather than slowing development by dilution, it is preferable to reduce the alkalinity to the minimum necessary for the developer to act. Developers containing hydroquinone need an effective buffer to limit the increase in the alkalinity resulting from the aerial oxidation of the hydroquinone in the presence of sulphite (§ 409). The use of borax is often sufficient with, or without, an excess of boric acid.

In order to reduce the maximum gamma (γ_{∞}) of the material to a level that is only slightly greater than the desired gamma value, and to reduce the effects of mistakes in working, the fine-grain developers are often doctored with a weak solvent for silver halide. Ammonium chloride (Lumière and Seyewetz, 1904) and ammonium sulphate (F. Burki and L. Jenny, 1943) can be used though, in order to avoid the loss of ammonia gas from the developer, non-volatile amines may be preferred, such as ethylenediamine hydrochloride (P. W. Wittum, 1935). Potassium thiocyanate (§ 665, P. Strauss, 1937) at about 1 g per litre may be used, or the sulphite concentration can be considerably increased (J. G. Capstaff, 1927).

The neutral, or slightly alkaline, phenylenediamine developers would be perfect if judged only on granularity, but these developers need a considerable increase in exposure. A number of factors lead to the view that development by the phenylenediamines is, to a large extent, physical (Lüppo-Cramer, 1936). It has been observed (F. Baldet, 1943) that in the neighbourhood of gamma 0.9, a sharp increase in the granularity of the image is manifested in these developers. An error of 30 seconds in the time of development or of 0.2°C in the temperature of the bath can cause the gamma to exceed the critical value.

Rather than choose a rapid, coarse-grained emulsion, whose high speed is largely sacrificed by using a fine-grain developer (which is always somewhat capricious), it is better to choose a slightly less rapid, finer-grained emulsion and to obtain its full emulsion speed by developing it in a solution of normal activity.

476. **Fine-grain Developer for Miniature Negatives.** The following developer (the Kodak D76 formula), has been extensively used for the development of motion-picture negatives and variable-density sound tracks, and, latterly, for the development of miniature negatives that often may require to be enlarged 10 to 15 diameters. A better-buffered variant (D76d) has been described (H. C. Carlton and J. I. Crabtree, 1930) which gives identical results when fresh ($pH = 8.4$) but which changes less rapidly on exposure to air. These developers are very susceptible to the influence of the soluble bromide formed by the reduction of the silver bromide.

	D76	D76R (replenisher)	D76d
Metal	2 g	3 g	2 g
Sodium sulphite, anhydrous	100 g	100 g	100 g
Hydroquinone	5 g	7.5 g	5 g
Borax	2 g	20 g	8 g
Boric acid (§ 480)	—	—	8 g
Water to make	1 litre	1 litre	1 litre

These developers owe their special properties to their very high sulphite concentration which, in the time necessary to reach a gamma of about 0.8 (being on average 12 minutes in a fresh bath at 18°C), dissolves an appreciable part of the silver bromide from each grain. The silver ions thus brought into solution are reduced and give rise to a silver deposit on the walls of the tank, etc., and to a sediment. The negatives are slightly fogged.

After developing about 20 ft of 35-mm negative per litre of the bath, the time of development should be increased by about 25 per cent.

If the replenisher is used, it should be added in quantities just sufficient to maintain the bath at constant volume. The bath should be rejected after adding a total quantity of replenisher equal to its initial volume.

In order to obtain an appreciably finer grain, the following developer may be used ($pH = 7.0$), which develops to a gamma of 0.8 in 40 minutes at 20°C. The exposure should be double that required when developing in D76 (R. W. Henn and J. I. Crabtree, 1944), i.e. double normal exposure.

	Developer	Replenisher
Metol	7.5 g	10 g
Sodium sulphite, anhydrous	100 g	100 g
Sodium bisulphite	15 g	—
Sodium metaborate	—	20 g
Water to make	1 litre	1 litre

Since this bath is very susceptible to the influence of bromide, the time of development should be increased by 15 per cent after developing 5 square decimetres (about 80 square in.) of film per litre of the bath. The bath should be rejected after developing 40 square decimetres ($4\frac{1}{2}$ square ft) of film per litre. On the other hand, the time of development can be maintained constant, the bath being rejected after 120 square decimetres (about 14 square ft) of film have been developed, by adding 9 ml of the replenisher solution after each square decimetre (16 square in.) of film, rejecting some of the used bath, if necessary, so that the level is maintained constant. This procedure should be followed until 60 square decimetres ($6\frac{1}{2}$ square ft) of film have been processed. The rate of adding the replenisher should be halved for the subsequent 60 square decimetres of film.

The very high concentration of sulphite in these developers leads to a very rapid exhaustion of chrome-alum stop baths if the negatives are not briefly rinsed on leaving the developer.

Various methods of large-scale developing in two baths, achieving more economically the results given by D76, are described in (§ 479), and in (§ 485), there is also a method of physical development for fine-grain work suitable especially for use by amateurs.

477. Two-bath Development. Development in two successive baths may be applied to achieve widely divergent, and opposed, ends.

It was very early applied for the correction of errors in exposure that became apparent at the moment that the image appeared (§ 445). Although this method of development is useful only in a limited field, an example will be described. Consider, as an extreme example, the expedient often recommended for increasing the development of the under-exposed shadows in a negative without making the density of the highlights too great. The negative is transferred to a dish of water that is vigorously rocked to dilute uniformly the developer carried over. The negative continues to develop, by virtue of the developer contained in the emulsion, except in the highlights where the developer is almost instantaneously exhausted. However, it would seem that this method is not always as effective as it is sometimes made out to be. The sensitometric experiments of J. I. Crabtree and H. A.

Miller (1939) have indicated that, in a case where the process has been claimed to be efficient, the transferring of the half-developed negative into an inert solution (water, glycerine, alkaline buffer) has given a result that could be exactly equalled by reducing the time of development by 25 per cent.

Two-bath development is employed industrially to obtain a greater uniformity of results than can be achieved in a single replenished bath, and with a more economical use of the developer chemicals. On the one hand the two successive baths may differ only by the state of their exhaustion, but on the other hand they can be of very different composition.

In the extreme case, two baths can be used, neither being, properly speaking, a developer, the complete developer being formed in the emulsion layer by the mixture of the developing agent solution, with which it has been impregnated, and the alkali from the second bath.

478. The following procedure (A. von Hübl, 1897), based on the visual control of development, is applicable only to non-colour sensitive emulsions and to those which have been desensitized.

25 g of anhydrous sodium sulphite and 20 g of glycine are dissolved in 70 ml of warm water; 100 g of crystallized potassium carbonate are added cautiously and, after the effervescence has ceased, the mixture is warmed until complete solution is achieved. It is then allowed to cool. Add water to make the volume up to 150 ml. The result is a light paste that should be stored in a well-stoppered bottle.

	Trial bath	For Negatives	
		Badly over-exposed	Badly under-exposed
Concentrated developer	42 ml	60 ml	30 ml
Potassium bromide (10 per cent solution)	2 ml	40 ml	—
Sodium hydroxide (10 per cent solution)	—	—	20 ml
Water to make	1 litre	1 litre	1 litre

The various developers are prepared by mixing. The negative is immersed in the trial bath which should be cooled to 10°C (50°F), if possible, when the development time will be one hour or more. On normally exposed negatives, the image appears in 15 minutes. In this case, development can be continued in the same bath or in one containing four times as much glycine and carbonate.

If the image appears in less than 10 minutes, the negative should be transferred to the bath for over-exposed negatives where, at 10°C, the development will be complete in less than an hour.

If no trace of the image, except the sky, is apparent after 30 minutes, transfer the negative to the bath for under-exposures where at 25°C (77°F) development will be completed in 10 to 15 minutes.

479. The following methods were studied in connexion with the industrial, fine-grain processing of motion-picture, and miniature negatives (J. I. Crabtree, H. Parker, and H. D. Russell, 1933).

The first procedure consists of the use of two, successive D76 developers (§ 476). The first bath is fresh and is maintained in practically new condition by topping it up to constant level with fresh developer. The film remains in the developer for a short time only. After 2 minutes in the fresh bath and 18 minutes in the second bath, both at 18°C, the same gamma (0.78) was obtained as resulted after 16 minutes in the fresh bath, the loss in speed being only 25 per cent, while the loss would have been 50 per cent had the film been developed entirely in the second, or used, bath. By rejecting the second bath and replacing it by the first bath, and using a new first bath, the cost of the chemicals was 33 per cent less than that for a single, replenished bath. By limiting the exhaustion of the second bath to 8 metres of cine film per litre (instead of 16 metres, in the above case), the consumption of chemicals was 33 per cent greater than in the case of a single bath, but the emulsion speed was 15 per cent greater.

The same workers studied the successive use of two developers of very different composition, the first (A) being a metol developer of moderate alkalinity ($\rho\text{H} = 9.0$), and the second (B) being D76.

	A	B
Metol	2 g	2 g
Sodium sulphite, anhydrous	100 g	100 g
Hydroquinone	—	5 g
Borax, crystalline	20 g	2 g
Water to make	1 litre	1 litre

A gamma value of 0.74 was obtained on the experimental film at 18°C after 3 minutes' immersion in A followed by 12 minutes in B. At the start, the speed was the same as that in a single, fresh bath of D76. The first bath was maintained at a constant level by topping up with fresh solution. The solution carried over on the film

served to replenish the second bath. After developing 16 metres of film per litre of bath, the loss in speed (30 per cent) was the same as that in D76 replenished with a volume of solution equal to that of the initial bath, and used to develop a total of 4.2 metres of film per litre of initial bath. However, the rate of development to the critical gamma was maintained constant.

480. Various workers have demonstrated the possibility of increasing the development of the shadows, while avoiding an excessive density in the highlights, by impregnating the emulsion with a sulphite solution of the developing agent and then transferring it to an alkaline solution. Sulphite is sometimes added to the alkaline solution to prevent a too-rapid oxidation of the developer diffusing into the bath, and bromide will appear in the solution as exhaustion proceeds (P. Joanovitch, 1907, A. Odencrants, 1922).

The sensitometric study of this method of development (J. I. Crabtree, H. Parker, and H. D. Russell, 1933) has shown an appreciable increase in useful emulsion speed and a sloping-off of the upper part of the characteristic curve. The maximum value of gamma is reached after 3 or 4 minutes in the second bath, this value being increased by a longer immersion in the first bath which allows the emulsion to absorb a greater quantity of developing agent. The development is produced almost entirely in the second bath. The first bath, which is unchanged by the film bathed in it, can be entirely used up.

The same workers studied the application of this method of working to fine-grain development in the case of motion-picture and miniature films. Since a sulphite solution of metol would develop without alkali (a gamma of 0.45 was reached after 16 minutes in the first bath) they slowed down its action, without changing the alkalinity, by adding sugar so that the image appeared in 4 minutes instead of 2 minutes.

The films used in their experiments reached a gamma of 0.52 at 18°C after 4 minutes in the A bath followed by 4 minutes in B. The graininess was the same as that given by D76, the fog being somewhat less than that found in D76, while the emulsion speed was about 40 per cent greater.

(A) Metol	5 g
Sodium sulphite, anhydrous	100 g
Hydroquinone	2 g
Sugar	100 g
Sodium bisulphite	5 g
Water to make	1 litre

$\rho\text{H} = 7.8$

(B) Sodium sulphite, anhydrous .	100 g
Sodium carbonate, anhydrous	100 g
Potassium bromide .	0.5 g
Potassium iodide .	0.01 g
Water to make .	1 litre

pH = 11.4

The first and second baths should be replaced after processing 45 metres and 22.5 metres of 35-mm film per litre, respectively. The first bath is affected mainly by the accumulation of bromide washed out of the film, and resulting from the reduction of the silver bromide dissolved by the sulphite. The second bath becomes increasingly charged with developer. Variations in the temperature of the A bath affect the swelling of the emulsion, thus changing the amount of developing agent absorbed. This factor, as well as the time of immersion in the first bath, leads to a variation in the gamma obtained.

481. Development in Tropical Climates. Various special precautions must be taken in hot climates. In the first place, development should not be deferred more than a few days, since the latent image sometimes suffers a gradual fading (regression) under the combined influence of high temperature and atmospheric moisture. Films are especially liable to this fading of the image. Next, the gelatine must be prevented from swelling excessively during the process; such swelling might lead to various troubles (melting, frilling, reticulation, etc.). Finally, sudden changes of temperature must be avoided with the swollen gelatine; these only increase the risk of accidents, and it is better to carry out the whole of the operations in baths at the surrounding temperature, even though it be high, than to use chilled baths for some parts of the process and warm water for others. In equatorial regions it is also advisable to carry out the work when the temperature is not so high, generally during the night.

Alum hardening before or during development (addition of chrome-alum to an amidol developer) often produces inequalities of development. It has been suggested that the sulphite content be reduced to about 13 grains per 20 oz (1.5 g per litre) in order to allow hardening of the gelatine by the oxidation products of the developer, but in this way only the gelatine in the image is tanned, and this action is also too slow when the gelatine has been able to swell already as is the case in hot climates.

It is well to call attention to the fact that methods which, in temperate and dry climates,

permit of the easy handling of plates and films up to 95°F, often fail when employed in hot and humid climates, producing reticulation at temperatures hardly greater than 80°F. This anomaly may perhaps be due to the considerable quantity of water vapour absorbed by the gelatine before development.

In order to prevent the swelling of the gelatine without preliminary hardening, addition is made to the developer (and to any baths such as desensitizers used before development) of 10 per cent to 20 per cent of sodium sulphate (§ 434); or alcohol is substituted for a certain proportion of the water.

As the result of a systematic study of a great number of developers used at various temperatures up to 95°F, J. I. Crabtree (1917) recommended the following developer—

Sodium sulphite, anhydrous .	50 g
Paraminophenol hydrochloride .	7 g
Sodium carbonate, anhydrous .	50 g
Sodium sulphate, crystals .	100 to 200 g
Water to make .	1 litre

The maximum quantity of sodium sulphate is employed only if the developer is at a temperature of about 95°F; at about 80°F the minimum amount stated is quite enough. A slight reticulation should be produced only after 4 or 5 minutes' immersion in the developer, a time greatly in excess of the normal duration of development, in spite of the retardation due to the sulphate. Development takes twice as long with the lesser quantity of sulphate stated and three times with the larger quantity.

Although this developer has little tendency to give chemical fog, it may be necessary, especially at the higher temperatures, to add to it a small amount of potassium bromide.

A slightly acidified amidol developer without any special addition may be used at temperatures up to 80°F and more, by reason of the very slight swelling of gelatine in acid baths. This developer may be adapted to temperatures up to 95°F by the addition of sodium sulphate as follows (L. J. Bunel, 1924)—

Sodium sulphite, anhydrous .	30 g
Potassium metabisulphite .	10 g
Amidol .	5 g
Potassium bromide .	5 g
Lactic acid (medicinal) .	5 cc
Sodium sulphate, cryst. .	100 g
Water to make .	1 litre

At higher temperatures than 95°F, sodium sulphate, even in larger amounts, no longer serves to prevent excessive softening of the gelatine,

and part of the water normally used for making up the developer must be replaced by alcohol.

Whatever the developer employed, rinse the developed negative very rapidly, and proceed either with temporary "fixing," according to § 451, or with fixing in a combined hardening and fixing bath (§ 492).

482. Ultra-rapid Development. In some special cases, e.g. in television, race-finish photography, and surgery under radiographic control, it is essential to be able to examine the image with the least possible delay that is compatible with obtaining an acceptable image. Since such results are only obtained to the detriment of the quality of the image, this method of working should be employed only in cases of extreme urgency.

One of the means employed in order to accelerate development is the use of high temperatures. Experiments have been made with special emulsions that can be developed at 50°–60°C. Another way is to use very alkaline developers in which, at 25°C, the emulsion can remain for only a few seconds before it starts to disintegrate. Then there is two-bath development (§ 477) in which one of the factors causing acceleration is probably the heat released in the emulsion layer by the formation of phenolates.

To develop in 10 seconds, Jaenicke (1937) has suggested plunging the negative for 2 seconds into a 5 per cent solution of hydroquinone containing 2.5 per cent of anhydrous sodium sulphite, and then for 2 seconds into a 30 per cent potassium hydroxide solution containing 0.1 per cent of potassium bromide and 1 part of safranin in 5,000 of the caustic bath to avoid aerial fog.

The negative material can be soaked in a hydroquinone solution, and then dried, before exposing it. In this case, development can be effected by immersing the prepared negative for 1 second in the alkaline solution. By dispensing with an intermediate rinse and proceeding directly to an alkaline hypo fixer, the fixing time could be reduced to 5 seconds (H. Jaenicke, 1940).

Better results are obtained by developing for 1 minute in an alkaline-hydroquinone process developer (§ 471) to which 10 ml of a 1/1,000 safranin solution and 10 ml of formalin are added. On the other hand a developer for under-exposed negatives (§ 466) may be used, to which, if it is for use in a continuous-processing machine, 10 g of sodium hydroxide are added per litre (H. Parker and J. I. Crabtree, 1936). The image is developed to a gamma value of about 0.55 and the loss of emulsion speed amounts to 10 to 15 per cent.

J. I. Crabtree and H. D. Russell (1944) particularly recommend the following method. After hardening the emulsion (§ 460) which requires 3 minutes, the image is developed in 15 to 30 seconds at 30°C in—

Methyl alcohol	50 ml
Metol	14 g
Sodium sulphite, anhydrous	50 g
Hydroquinone	14 g
Sodium hydroxide	17.5 g
Potassium bromide	9 g
Water to make	1 litre

In cases of extreme urgency, the negatives may be examined after a brief immersion in the stop bath, or after iodizing (§ 451).

When it is necessary to make prints, fixing should be carried out in a warm, agitated bath. After a brief rinse, the wet negative should be enfolded in a sheet of thin cellulose-acetate film so as to avoid contact, during printing, between the paper and the fixing solution. On the other hand the negative can be projection-printed using an enlarger with a carrier, without glass, which can hold the wet negative.

483. Combined Developing and Fixing. It is possible to carry out in a single bath, the development and fixing of a negative plate or film (papers cannot be treated this way without heavy fog resulting). This fact was known to W. D. Richmond (1889). It is, however, only in recent years that it has been possible to obtain satisfactory results this way, and even then only in certain cases. For one thing, many emulsions, in order to give passable results, must be given considerable over-exposure. A further difficulty is that development and fixing are not equally affected by temperature variation. Fixing is retarded by heat and accelerated by cold more than is the case with development (C. E. K. Mees, 1921). This causes increased development in cold baths.

Improving on the methods of C. Otsuki and T. Sudzuki (1914) and L. J. Bunel (1921), A. and L. Lumière and A. Seyewetz, (1924) recommended the following bath in which development and fixation are completed in 15 to 20 minutes at temperatures between 60° and 65°F. (About 50 ml are required for a quarter plate)—

Sodium sulphite, anhydrous	4 g
Amidol	0.5 g
Sodium phosphate, tribasic	2 g
Hypo	2.5 g
Water to make	1 litre

When the solution has been used once it must be discarded.

PHYSICAL DEVELOPMENT BEFORE OR AFTER FIXING

484. Physical Development before Fixing. Physical development, which consists in the deposition of nascent silver, formed in the developer, on the nuclei of the latent image, and which is the normal method employed for the development of the image in the wet-collodion process, is also applicable to gelatine-bromide emulsions. As a rule, however, the method has no advantages over ordinary chemical development. The method of physical development is not always applicable to ortho- or panchromatic emulsions, nor to ordinary emulsions after desensitization, because the dyes absorbed by the nuclei of the image sometimes prevent development (Lumière and Seyewetz, 1924).

The precipitation of silver may be brought about in solutions which are alkaline, neutral, or acid. One of the most commonly employed methods is that of Lüppo-Cramer (1903, 1923).

The stock solution is prepared as follows—

Metol	15 to 20 g
Citric acid	100 g
Sodium citrate	15 g
Water to make	1 litre

The formation of mildew in this solution may be prevented by the addition of a small quantity of phenol. When required for use, take 100 ml of this solution and add from 3 to 10 ml of a 10 per cent solution of silver nitrate. Development is very slow. As soon as the developer becomes turbid it must be replaced by a fresh quantity.

Plates of recent manufacture must be used and the exposures given must be large. One condition of success is that all dishes employed must be quite clean; it is best to use a glass dish which has been very carefully cleaned.

It has been proposed (A. Schmidt, 1896) that when a plate has been found to be over-exposed chemical development should be stopped at once by washing in water, the plate being then treated by a physical developer.

485. Semi-physical Fine-grain Development. Lüppo-Cramer (1921) noted that physical development is accelerated, and does not require a heavy over-exposure, when the silver bromide has been superficially iodized, the disturbance of the grain surface allowing access of the developer to the latent-image specks that are formed in the interior of the grains (denudation of the latent-image nuclei). This method has been applied to miniature negatives for physical

development before fixing in order to obtain fine-grain images (A. F. Odell, 1933). The negative should be given double the exposure that would be required for normal development. This loss in speed could be largely avoided by prolonging the development, but this would adversely affect the granularity.

The iodization is achieved by immersing the negative for a maximum time of 60 seconds in a solution containing 1 per cent of potassium iodide and 2.5 per cent of anhydrous sodium sulphite. The negative should then be well rinsed.

The developer is prepared immediately before use by dissolving 1.5 g of amidol in 800 ml of water and adding 200 ml of the following stock solution—

Sodium sulphite, anhydrous (20 per cent solution)	400 ml
Silver nitrate (4 per cent solution)	500 ml
Sodium thiosulphate (hypo)	150 g

The hypo is added after the precipitate of silver sulphite has redissolved in the excess of sodium sulphite. The pH of the solution should be between 9.2 and 9.3. It may be increased, if necessary, to bring it to the correct value by small additions of very dilute ammonia solution. If the pH cannot be checked, a quantity of borax, equal in weight to the silver nitrate, should be added (F. R. McQuown, 1939).

The development, which is complete in about 30 minutes, is accompanied by some chemical development. The straight-line portion of the characteristic curve is slightly longer than in the case of chemical development (P. V. Turner, 1938). The image has a light grey appearance, so that, after fixing, it appears as a positive when viewed by reflected light against a dark background.

486. Physical Development after Fixing. The possibility of developing after fixation was established in 1858 for wet-collodion plates by Young and in 1894 for gelatine-bromide plates by Kogelmann.

The negatives should be well over-exposed, more so for materials of high emulsion speed. The fixing bath should be made alkaline, or sulphite should be added to limit the tendency of the thiosulphate to attack the silver forming the latent image.

The following procedures (A. and L. Lumière, and A. Seyewetz, 1911; 1924) yield silver and mercury images respectively. The negative is fixed in a 30 per cent solution of sodium thiosulphate to which 1 per cent of concentrated

(20 per cent solution) ammonia solution has been added. After a maximum of 5 minutes the fixed negative is washed in several changes of ammoniacal water, then, for the last time, in plain water. After the fixing is complete, all operations can be carried out in white light.

The developer is prepared, immediately before use, by mixing 5 volumes of one of the A solutions with 1 volume of the corresponding B solution—

	Silver	Mercury
(A) Sodium sulphite, anhydrous .	180 g	180 g
Silver nitrate, 10 per cent solution	75 ml	—
Mercuric bromide	—	9 g
Water to make	1 litre	1 litre

(B) Sodium sulphite, anhydrous .	20 g	20 g
Paraphenylenediamine (free base)	20 g	—
Metol	—	20 g
Water to make	1 litre	1 litre

The image appears slowly and reaches a printable gamma only after several hours, the bath being renewed every hour. The image is light grey by reflection and grey-violet by transmitted light. After developing for 30 minutes, an image of sufficient contrast for printing can be obtained by intensification.

An old negative, from which the mercury has evaporated, can be restored by developing it again (H. Leffman, 1923).

CHAPTER XXIX

FIXATION

487. The Purpose of Fixation. Fixing and washing are necessary in order, firstly, to convert the salts of silver remaining in the image, after its development, into soluble substances, and, secondly, to remove them. Contrary to common opinion, the former of these processes is by far the more important; washing, no matter how prolonged, can only remove soluble substances, and is not effective if the previous process of solution has not been carried to completion by fixing.

It should be mentioned that after as perfect a fixing as possible there always remains, under the greatest densities of the image, a very small amount of silver bromide, which can be developed or dissolved after the silver of the image has been eliminated by a sulphuric solution of permanganate.

488. Solvents of the Silver Halides. It must be said at the outset that there are no true solvents of the chloride, bromide, or iodide of silver. When sugar is dissolved in water and the latter is evaporated, spontaneously or by boiling, the sugar is recovered in its original condition; this is really a case of true solution. If silver bromide be submitted to the action of one of the saline solutions which are generally considered as its solvents, the evaporation of the liquid so obtained will never leave behind silver bromide; the residue will consist of transformation products of this salt, due to the chemical interaction of the silver salt and the fixing salt. This fine distinction is of great practical importance.

The first practical fixer to be used was sodium thiosulphate (then known as hyposulphite of soda, hence "hypo") employed for this purpose by Herschel (son of the astronomer) in 1839. Sodium thiosulphate, though it deals effectively with the silver chloride and bromide is only a very mediocre fixing agent for photographic coatings containing mainly silver iodide. It was abandoned on the introduction of the wet collodion process, in which fixing was done by a solution of potassium cyanide. Potassium cyanide is now almost entirely replaced by sodium

cyanide. Both of these salts, even in very small amounts, are extremely dangerous poisons, if absorbed by the mouth or through a scratch in the skin. Exposed to the air, their solutions slowly liberate hydrocyanic acid, which by accumulating in a badly ventilated place—as many photographic darkrooms are—may cause indisposition or even serious illness. Sodium thiosulphate returned to favour when the gelatine-bromide plate replaced, except for certain special applications, the collodion processes. It may be considered as being practically the only fixer in common use.

The various other substances capable of converting the halides of silver into soluble substances are considerably more difficult to use. The solutions so obtained are not very stable and are precipitated on dilution, and do not permit of final removal by washing. This is notably the case with ammonia (ineffective for iodide of silver), with sulphites and bisulphites (only slightly active), with sulphocyanides (thiocyanates), with thio-urea and its derivatives.

489. Sodium Thiosulphate. Sodium thiosulphate (or hyposulphite) ($\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$) occurs in crystals of varying size, of specific gravity 1.7, containing 64 per cent of the active substance (anhydrous thiosulphate) and 36 per cent of water. It is deliquescent in moist air and very soluble in water, but insoluble in alcohol. It melts at about 122°F in its own water of crystallization, and is completely dehydrated by heating to a temperature above 212°F , but this leads to partial decomposition unless special precautions are taken, and thus the price of anhydrous thiosulphate is rather higher than that of crystalline.

On dissolving in water, sodium thiosulphate lowers the temperature; for this reason the preparation of solutions should not be left until they are required for use. For making up quantities of sodium thiosulphate on the commercial scale, a Baumé hydrometer should be used, together with the following table, which refers to a temperature of 60°F —

Concentration of solution	10%	15%	20%	25%	30%
Degrees Baumé	7°	10°	12.5°	15°	18.5°

¹ Throughout this chapter "thiosulphate" will be used when making a specifically chemical reference; "hypo" is used when dealing with sodium thiosulphate, especially in matters of fixing practice.

Solutions of thiosulphate decompose slowly,

even when kept from air and light; sulphur is deposited, whilst a little sulphite is formed in the solution.

With very few exceptions, acids (even the weakest) and acid salts decompose thiosulphate more or less rapidly, according to the concentration and strength of the acid. This decomposition manifests itself by the gradual formation of sulphur, which is set free in such a condition (colloidal sulphur) that it is only seen with difficulty. The particles unite with one another, and at first a bluish opalescence appears, then a white turbidity, and finally a yellow precipitate is formed; at the same time sulphur dioxide and sometimes sulphuretted hydrogen are set free, whilst in the solution sodium sulphate and thionates (Seyewetz and Chicandard, 1895) are formed. Once started, this decomposition goes on until the thiosulphate is completely destroyed.

Among the common acids and acid salts, boric acid and sodium bisulphite alone cause no decomposition of thiosulphate solutions; or at any rate, the decomposition is so slow as not to occur during normal times of storage. However, sulphiding of sensitive plates or papers has been noted in a darkroom, where a dish is always kept containing such acidified fixing baths.

This property of sodium bisulphite in relation to thiosulphate causes sodium sulphite to behave as a protector of thiosulphate against acids. The latter are not able to attack the thiosulphate until all the sulphite has been converted into bisulphite.

Neutral or acidified solutions of thiosulphate attack a great many metals, the action being particularly rapid in the case of zinc, so that zinc washing trays are quickly corroded when used continually. Nickel is only slightly attacked, and tanks of this metal may therefore be used for fixing baths, provided that the solutions are removed when fixing has been finished. For commercial use, tanks of wood, glazed earthenware, or even of lead, lapped and self-soldered, are employed. The addition of 1 per cent sodium sulphate to fixing baths prevents or retards considerably the attack of acid fixers on lead (G. Milliani, 1921) without interfering with the normal course of fixing.

Neutral thiosulphate solutions attack metallic silver only very slowly, even when it is in such a finely divided condition as in photographic negatives; even then, free access to the air must be allowed for the action to occur (Haddon and Grundy, 1896). There is no harm in leaving

photographic images for several hours in a neutral fixing bath, provided that the negatives or prints are fully covered with solution; an appreciable reduction would appear on any portions sticking up from the liquid or lying on the surface.

Acid solutions of sodium thiosulphate, on the other hand, slowly attack metallic silver (A. Lainer, 1890) without the intervention of atmospheric oxygen, the solution of all the silver in a negative sometimes being complete in 48 hours. Leaving negatives or prints for long periods in acid fixing baths is therefore to be avoided.

Alkaline thiosulphate solutions have practically no action on the silver of photographic images. The silver of images fixed with sodium thiosulphate contains traces of some sulphur compound not yet identified. After dissolving away the silver by means of suitable reagents, this substance remains in the coating in the form of silver sulphide (Lüppo-Cramer, 1923).

490. The Chemistry of Fixation. When a very small quantity of thiosulphate comes in contact with a large excess of a salt of silver it tends to form silver thiosulphate; this salt is unstable, like almost all thiosulphates, and decomposes quickly into brown or black insoluble silver sulphide and sulphuric acid, which remains in solution. This explains the stains formed on sensitive surfaces, particularly on print-out papers (containing soluble silver salts), when they are touched by fingers soiled with hypo.

It is quite otherwise when the salt of silver comes in contact with a large excess of hypo in sufficiently concentrated solution. Again, silver thiosulphate tends to be formed, but this salt combines at once with excess of sodium thiosulphate, forming *complex thiosulphates of silver and sodium*. These salts are comparatively stable and are sharply differentiated in all their properties from a *mixture* of the two simple thiosulphates. For example, these complex thiosulphates have a sweet taste, whilst sodium thiosulphate has a bitter and sulphurous taste, and the salts of silver generally have a disagreeable metallic taste.

The composition of these complex salts appears to vary according to the nature of the salt of silver which is caused to react with sodium thiosulphate (Gaedicke, 1903; Lumière and Seyewetz, 1907). Whatever the original salt of silver, however, according to the proportions of hypo and of the silver salt, one may always obtain either a soluble complex thiosulphate or an insoluble complex thiosulphate.

The formulae of these salts are respectively (H. Baines, 1929)—

(A) Insoluble complex thiosulphate
 $\text{AgNaS}_2\text{O}_3, \text{H}_2\text{O}.$

(B) Soluble complex thiosulphate
 $\text{Ag}_3\text{Na}_5(\text{S}_2\text{O}_3)_4, 2\text{H}_2\text{O}.$

Solutions of complex thiosulphates may be caused to deposit the complex salt (B) (e.g. by the addition of alcohol), whilst solutions saturated with silver deposit spontaneously the insoluble salt (A).

It is obvious that it is the formation of the soluble complex thiosulphate which must be aimed at during fixing, because only a soluble salt can be removed by washing. The soluble complex thiosulphates contain, for a given quantity of silver thiosulphate, a higher proportion of sodium thiosulphate than the insoluble thiosulphate; their formation requires the presence of a large excess of *available* sodium thiosulphate, which is not already saturated with salts of silver.

These complex salts decompose spontaneously in the cold, depositing silver sulphide; this decomposition is very rapid in the absence of an excess of hypo and is accelerated by heat and light. The soluble complex salt is decomposed in a pure aqueous solution if its concentration corresponds to more than 3.24 per cent of metallic silver, the greater its concentration the greater the excess of hypo required to render it stable (E. Römmler, 1929). It is well known that used fixing baths deposit in time a black sludge consisting mainly of sulphide of silver.

The rules which must be followed in order to ensure the effective fixation of photographic plates, films, and papers follow logically from these facts.

491. The Mechanism of Fixation. The mechanism of fixation has been studied specially by Sheppard and Mees (1906) and by Warwick (1917). These workers used very different experimental methods, but arrived at identical conclusions, which are in conformity with the general laws of physical chemistry.

A fixing bath dissolves per unit time a constant fraction of the mass of silver bromide existing in the coating at the commencement of the interval of time considered.

The magnitude of this fraction depends on the temperature and on the effective concentration of the bath; it is independent of the silver content of the emulsion, of the quality of the gelatine, of its degree of swelling, and even of

previous hardening of the film; it is greater for silver chloride than for the bromide, and for the bromide than for the iodide; for the same silver salt it is greater if the emulsion is one consisting of fine grains.

The disappearance of the milky layer of silver bromide does not indicate that the solution of this substance is complete, but only that the opalescent layer is so much reduced as to be invisible; at this instant there may still be more than 5 per cent of the original silver halide undissolved. Some very ingenious experiments by E. R. Bullock (1922) appear to show that when fixing emulsions consisting of silver iodobromide, the silver bromide is almost totally dissolved when the solution of the iodide is beginning.

In the same way that the best time of development may be determined by multiplying by a suitable factor the time taken for the first details of the image to appear (§ 381), so, by multiplying the time of disappearance of the silver bromide by a factor, the time necessary to give satisfactory fixation may be calculated. The best margin of safety is obtained, when single-bath fixation is employed, by keeping the negative in the fixing solution after the apparent disappearance of the silver bromide for a time equal to that taken for the milkiness to disappear. If, for example, at the time of disappearance of the visible silver bromide 95 per cent of this salt has been dissolved, keeping the negative in the bath for another period equal to the first will allow of the solution of 95 per cent of the residual silver bromide, which is no more than 5 per cent of the original amount present. Thus $95 + 4.75 (= 99.75)$ per cent will be dissolved; the residue, amounting to more than 0.25 per cent of the original quantity of silver bromide, will be partially dissolved in the first of the washing water since the latter soon takes up a sufficient quantity of sodium thiosulphate to behave as a supplementary fixing bath.

The curves in Fig. 29.1, taken from the experiments of Warwick, show, for a surface of 1 sq dm of negative emulsion of average coating weight, the quantities of silver bromide (expressed in weights of metallic silver) to be dissolved and already dissolved at the various stages of fixing in a 20 per cent solution of hypo at 65°F. The curves shown as heavy lines refer to an undeveloped plate; the finer lines refer to a developed plate. A study of the curves shows the gradual progress of fixation.

492. Additions to Fixing Baths. At the instant of plunging negatives or prints into the fixing bath, the gelatine (and in the case of papers the base also), in spite of intermediate rinsing, is impregnated with the developing solution, especially in the deeper layers of the film. There is thus danger of development continuing in irregularly-distributed zones. Further, the accumulation of these substances in the fixing bath as more and more negatives are treated

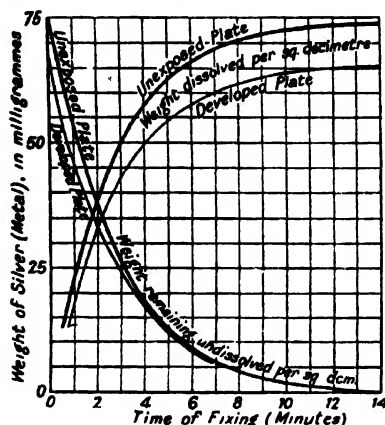


FIG. 29.1. STAGES OF FIXING

(Warwick)

tends to produce troubles such as dichroic fog (§ 433) or general coloration of the gelatine by the oxidation products of the developer. Lastly, under these conditions, the fixing bath would become slightly alkaline, and it is in such alkaline media that maximum swelling of gelatine occurs, so that it becomes very tender and tends to reticulate (§ 434). These difficulties may be avoided by acidifying the fixing bath to a slight extent by the addition of sodium bisulphite (J. M. Eder, 1889), or of acetic acid in presence of sodium sulphite, (A. Lainer, 1889) or of boric acid (H. Reeb, 1906; J. I. Crabtree, 1933).

Sheppard, Elliot, and Sweet (1923) showed that whenever considerations of cost do not prohibit the use of acetic acid, the mixture of this acid with sulphite is much the best; in presence of the acetate of sodium so formed the free acidity corresponds to only a fraction of the total available acidity, the difference forming a reserve of acidity.

An objection sometimes made to the use of

acid baths is that the exhaustion of the solution is masked, and that thus there is a risk that the bath may be used beyond its power, the permanence of the images not being ensured. A neutral bath soon begins to become discoloured by the oxidation products of the developer and to throw down a brown sludge of silver sulphide and reduced silver, changes which suggest the necessity of replacing the old bath by a new one within a reasonable time.

When the temperature of the bath or of the wash water, or of the air in which drying is to be done, rises above 68°F, it is advisable to harden the gelatine. From every point of view it is best in such cases to combine this operation with that of fixation by adding an alum to the fixing bath. It remains, therefore, to decide which of the two available alums, ordinary alum (white) or chrome-alum (violet), is preferable. Taking into account only hardening efficiency, chrome-alum should be chosen, and this is, in fact, always used in very hot climates; its price is, however, considerably greater than that of ordinary alum, and also certain printing papers when treated with chrome-alum retain—even after washing—a very slight green tint.

After treatment with alum, the tendency of gelatine to swell is greatly reduced, and its melting point is very considerably raised, sometimes to a temperature above 158°F.

In a warm and moist atmosphere spontaneous drying is generally slower than the growth of liquefying bacteria. Gelatine which has been suitably treated with alum will resist even the heat of direct sunshine, and drying can then be sufficiently rapid to prevent local liquefaction (L. J. Bunel, 1924). Gelatine may be hardened by solutions of formalin (formaldehyde), but, whilst cases of slow alteration, physical or mechanical, are rare with alum-hardened gelatines, several have occurred in which formalin-treated gelatines have become brittle or even powdery. Thus it is advisable, except for negatives or prints which are of merely passing interest, always to avoid the use of formalin or its derivatives (trioxymethylene, etc.). Formalin is much more effective in a solution rendered alkaline (ammonia must not be used) than in a neutral or acid solution, and may, therefore, then be used at a greater dilution; rinse in water after each immersion in formalin. It may be added that formalin is very irritating to the eyes and the lungs, has a very unpleasant smell, and causes an objectionable hardening of the skin. Very many other substances with an

aldehyde character (hydroxyaldehydes, dialdehydes, etc.), can be employed for hardening gelatine.

493. The Chemistry of Fixation in the Presence of Alum. Ordinary alum $\text{Al}_2(\text{SO}_4)_3 \cdot \text{K}_2\text{SO}_4 \cdot 24\text{H}_2\text{O}$, occurs in large crystals or, more commonly, as a white powder obtained by crushing the crystals. The solubility in water is about 9 per cent at 50°F, 13 per cent at 68°F, and 30 per cent at 104°F. The salt and its solutions are stable. The active substance in it is the aluminium sulphate which may, in fact, be used in place of it in proportion of two parts of aluminium sulphate to three of alum.

Chrome-alum, $\text{Cr}_2(\text{SO}_4)_3 \cdot \text{K}_2\text{SO}_4 \cdot 24\text{H}_2\text{O}$, usually occurs in large dark-violet crystals of satisfactory purity. The substance itself and its solutions are very stable; at the most the crystals lose a little water from the surface, becoming covered with a grey powdery layer. Its solution, when prepared cold, is greyish-violet, becoming green when warmed. This change of colour accompanies a modification in the internal structure of the salt, but this leads to no appreciable alteration in its hardening power. Chrome-alum is more soluble than common alum, especially on warming the mixture so that the change to green occurs; the solubility then becomes more than 50 per cent at 68°F.

The reactions of ordinary alum with sodium thiosulphate have been studied very completely by Seyewetz and Chicandard (1895); the reactions are almost the same with chrome-alum.

On prolonged boiling, hypo and alum are mutually and completely decomposed; sulphur and alumina are precipitated, sulphur dioxide is liberated, and sodium sulphate is formed in solution.

In the cold the reaction is different; aluminium thiosulphate tends to be formed. This substance is very unstable, and breaks down into aluminium sulphate and hydrogen sulphide. The latter, by reacting with excess of sodium thiosulphate, slowly yields sodium bisulphite and sulphide with precipitation of sulphur. The aluminium sulphate being regenerated, the same reaction is repeated, but always slowly; because of the protective action of the sodium bisulphite, which is formed and which is only very slowly converted into thionates. The acceleration of these reactions on warming the mixture is made use of for the sulphide toning of prints on development papers (§ 736).

These reactions may be prevented or, at least,

very much retarded, by the addition of sodium sulphite or bisulphite (Seyewetz and Chicandard), or of sodium acetate or citrate (P. Mercier, 1894).

Hardening by alums is favoured by neutral or alkaline conditions, but when a mixture of ordinary alum and hypo is stabilized by sulphite, acid must be added, otherwise a white precipitate of aluminium sulphite will be deposited. This deposition of aluminium sulphite would occur, especially within the gelatine, on account of the alkali of the developer carried over with the negative, and this precipitate would be very difficult to remove.

For the different reasons given in the preceding paragraph and above, an alum fixing bath must be acid to a sufficient extent to prevent precipitation of aluminium sulphate, even after a comparatively large quantity of developing solution has been added to it. It must, however, not be so acid as to decompose the hypo.

Hardening by alum is considerably reduced by the action of oxalic, tartaric, or citric acids, or of their salts, especially at high concentrations. Acetic, formic, and analogous acids and their salts are free from this drawback. Alum-hardened gelatine may even be de-tanned by immersion for some time in a 5 per cent solution of citric acid (Proctor and Wilson, 1916).

494. Fixing Capacity of Thiosulphate for Silver Halides. Sodium thiosulphate does not dissolve with equal facility the different silver salts occurring in an emulsion. Moreover, the power of the same weight of hypo to dissolve the same silver salt increases as its concentration is raised. The following values correspond with saturation of the hypo after long mechanical agitation, gelatine being absent (Richards and Burnells Faber, 1889)—

Concentration of Hypo	Weight of halide dissolved per litre		
	Silver chloride	Silver bromide	Silver iodide
10%	41 g	37 g	3 g
20%	91 g	76 g	10 g
50%	—	213 g	—

Under normal conditions of photographic practice the dissolving power of hypo is considerably less.

Almost all modern negative emulsions contain silver iodide, which is present also in some positive emulsions (notably in positive motion-picture emulsions). This iodide tends to lower considerably the fixing power of hypo. The inactivity of hypo towards silver iodide explains the slow fixation of certain very sensitive emulsions, and especially anti-halation plates having a substratum of silver iodide.

	Weight of silver bromide (mg) dissolved per litre of saturated solution	Weight of silver bromide dissolved in 1 litre of bath without subsequent stain	Weight of silver bromide dissolved in g per g of hypo	Average number of 9×12 cm negative fixed per litre without subsequent stain
Sodium thiosulphate 5%	20	12.5	0.250	33
Sodium thiosulphate 15%	63	38	0.253	100
Sodium thiosulphate 45%	205	50	0.111	133
Sodium thiosulphate 15% and 1.5% bisulphite	61	16.5	0.110	45
The same with 0.5% chrome-alum	59	22	0.147	60

It must also be remembered that every plate, film, or print introduced into the fixing bath, brings with it a certain amount of water and takes away with it an approximately equal amount of the fixing solution, when it is transferred to the washing tank. Thus the bath is gradually diluted, and at the same time the total amount of available hypo decreases much more rapidly than it would do merely on account of the reaction of sodium thiosulphate with the silver salts.

By putting more and more negatives or prints into a fixing bath in an attempt to saturate the solution with silver salts, the disappearance of the silver salts would be rendered very slow, and the last samples to be fixed in a reasonable time would certainly become yellowish after some days, due to silver sulphide, formed from the insoluble complex thiosulphate and occurring fairly uniformly throughout the gelatine layer.

The first determinations in this field having an immediate practical bearing on photography were those of Lumière and Seyewetz (1907). These authors did not confine themselves to the determination of the maximum solubilities of silver bromide in pure hypo, hypo with bisulphite, with and without chrome-alum; they also determined the silver content at which any of these baths must be considered as unsuitable for further use, at least when fixation is carried out in a single bath.

The above table summarizes the results.

These results show that with single-bath fixation the efficiency of action of the hypo decreases as its concentration increases, and is still further depressed by acidification of the bath, especially in the absence of alum.

It is somewhat curious that, in spite of the fact that silver chloride is more soluble than the bromide in sodium thiosulphate, the practical limit of fixation is more rapidly reached in the case of the chloride; solutions of hypo saturated with silver chloride more easily deposit the insoluble complex thiosulphate.

495. Speed of Fixation—Various Factors. The influence of the concentration of the bath and

its temperature on the rate of fixation has been very carefully investigated by Welborne Piper (1912-1914); the two graphs (Figs. 29.2 and 29.3) show, for a given emulsion, the nature of the variations which occur when the first phase of fixation (disappearance of the milky film of halide) in pure sodium thiosulphate is considered.

It is seen that whatever the concentration of the fixer, the process is most rapid at the higher temperatures, and the greatest speed is always obtained at a concentration of 40 per cent. At higher concentrations fixation becomes slower as the concentration rises, on account of the increased difficulty with which these solutions diffuse into the gelatine.

The experiments of this author comparing the thiosulphates of sodium, potassium, ammonium, and calcium showed that for each thiosulphate fixation is most rapid at a certain concentration. For the sodium and ammonium thiosulphates the optimum concentrations are respectively 40 per cent and 15 per cent; the duration of fixation is the same for both at a concentration of 33 per cent; at lower concentrations than this the sodium salt acts more slowly, but more rapidly at higher concentrations. For example, at 20 per cent concentration the ammonium salt fixes five times more quickly than the sodium salt.

The rate of fixation is reduced as the bath becomes charged with more silver; the following table (P. Strauss, 1925) shows the influence of silver salts on the time of disappearance of silver bromide in a 25 per cent solution of hypo.

Silver salt dissolved per 100 ml of bath	Silver bromide	Silver chloride
0	73 sec	73 sec
1 g	92 "	92 "
2 g	101 "	94 "
4 g	121 "	112 "
6 g	239 "	204 "

Silver chloride retards fixation less than an equal weight of the bromide, despite the fact

that the chloride contains 75 per cent of silver and the bromide only 57 per cent. From this it is evident that the exhaustion of the bath,

addition of ammonium chloride to a solution of hypo allows it to dissolve more silver iodide.

The accompanying graph (Fig. 29.4) summarizes the observations of Welborne Piper (1914) on this subject. It is seen that for each concentration of hypo there is an optimum concentration of ammonium chloride. This optimum becomes smaller as the concentration of hypo is increased.

The acceleration of fixation by the addition of ammonium salts is, however, counterbalanced by a disadvantage (Lumière and Seyewetz, 1908). The complex thiosulphates of silver and ammonia formed under these circumstances are much less stable than the complex thiosulphates of sodium and silver; the practical limit of use is only about half, and the risks of discoloration of the image are increased. This acceleration, although advantageous in cases of

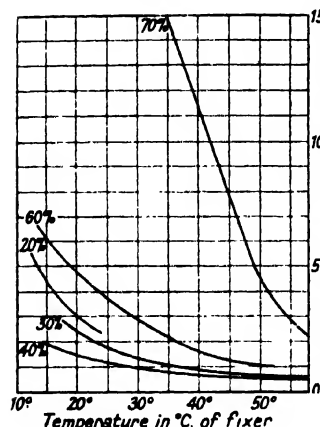


FIG. 29.2. VARIATION OF FIXING ACTION WITH TEMPERATURE (Piper)

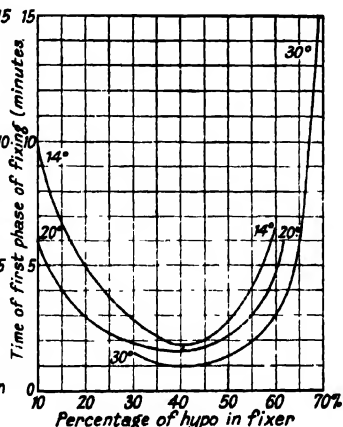


FIG. 29.3. VARIATION OF FIXING ACTION WITH STRENGTH OF HYPO BATH (Piper)

caused by the formation of silver thiosulphate, is not the only factor to be considered, but that the rate of fixation must be influenced by other salts arising from the reactions occurring. As a matter of fact, the addition of sodium bromide to the bath retards fixation, whilst sodium chloride accelerates it.

By reason of the very small solubility of silver iodide, the presence of a very little iodide in a solution of hypo is sufficient to retard fixation considerably; the following table shows the retarding influence of this salt on a 25 per cent solution of hypo.

Potassium iodide in 100 ml of the bath	0.00	0.02	0.05	0.11 g
Time of fixation	73	91	147	358 sec

Sodium sulphate slightly retards fixation, and all the salts of the heavy metals (copper, lead, etc.) behave in the same way. The nitrates of sodium or potassium accelerate fixation when present in small quantities, but at concentrations of 4 per cent or above they retard it. The salts of ammonia, particularly the chloride (ammonium chloride, or sal ammoniac), have a very strong accelerating action, which is, however, not so great with emulsions containing silver iodide (Agfa, 1906; Lumière and Seyewetz, 1908 and 1924), in spite of the fact that the

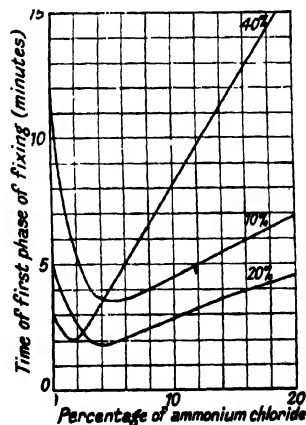


FIG. 29.4. EFFECT OF AMMONIUM CHLORIDE ON RATE OF FIXING (Piper)

extreme urgency, has no practical application in ordinary work, particularly when negatives are to be kept.

496. Fixation in Two Successive Baths. In all industrial operations involving the extraction of a substance by a solvent, the mass to be treated is at first extracted with solvent already almost saturated in previous operations, fresh solvent being used only to extract from material which is almost exhausted. Often, indeed, the process is made continuous by causing the solvent to circulate in the opposite direction to that of the material to be treated. This method of systematic extraction, which allows a solvent to be used most efficiently, may be applied with advantage to photographic fixation; it permits of making the most of a solution of hypo whilst giving perfect fixation and permanence of the images. Furthermore, it has the advantage that the residual silver salts are left at higher concentration, and therefore may be recovered more economically, such recovery being always carried out more easily when the substances are in concentrated solution.

In 1894 A. Miethe, on the basis of the experimental results of Haddon and Grundy, recommended fixation in two successive baths, separated by a brief rinsing. Under these conditions the first bath may be used well beyond the normal limit possible when fixation is carried out by the single-bath method. In fact, this bath will not be discarded until the first phase of fixation, indicated by the disappearance of the milky layer of silver halides, occupies an abnormally long time. It is true a portion of the silver will remain in the form of the insoluble thiosulphate, but during the second stage of fixation carried out in a solution of hypo which is almost fresh, the complete solution of the silver salts will be effected. Negatives treated by this process will be fixed as well as if a fresh bath of hypo had been used from the start.

Since the negatives reach the second bath almost completely fixed, there is little more to be done, and thus the practical limit of safety is not attained. When the first bath has to be abandoned, the second is made the first and is itself replaced by a new one.

Negatives are taken from the first bath when there appears to be no more silver bromide to dissolve; they are then placed in the second bath and allowed to remain for about the same time as in the first bath.

497. Choice of the Best Concentration of Fixer. The amateur, having to develop only one or two negatives, and not wishing to keep the bath for subsequent use, will preferably use a fairly

dilute bath, for example, 15 per cent hypo (150 g in 1 litre of water).

The professional or commercial worker, working almost continuously and using the two-bath method, will be well-advised to use much more concentrated solutions, which may be used until almost completely exhausted.

If speed of fixation only be considered, it would appear best to use a 40 per cent solution (§ 495), but other factors lead to the use of a less concentrated bath.

For one thing, the sudden change of concentration on passing from a too-concentrated fixing solution to the washing water, especially if the water is comparatively warm, may cause frilling or reticulation with plates and films, or blisters with papers. For another, if white light falls on the sensitive coatings during fixation, and if the concentration of the fixer be more than 30 per cent, there may occur in the film a slight insoluble residue which will not disappear, however long the negative or print be left in the fixing bath; at concentrations above 50 per cent, this insoluble residue may form even in the dark (Welborne Piper).

For these different reasons fixing baths are usually employed at concentrations between 20 per cent and 30 per cent, i.e. 200 g to 300 g of sodium thiosulphate (hydrate) per litre of bath.

498. Tests for Exhausted Fixer. When fixation is carried out by the single-bath method it is obviously only possible to calculate the area of sensitive material which has been fixed by a given volume of the bath. This calculation is, however, not likely to be of any value, unless data are available concerning the amount of silver in the emulsions used and the volume of the solution removed by the plates, etc., already fixed.

It is sometimes considered that a fixing bath has reached its limit of safety when the time of fixation of a given emulsion becomes double that required with a fresh bath at the same temperature. As a matter of fact, this method of testing results in carrying the use of a fixing bath considerably beyond reasonable limits, and would be more suitable for deciding the exhaustion point of the first bath in the case of two-stage fixation.

More accurate indication is obtained by employing a method of direct control suggested by Gaedicke in 1906, and recommended by Lumière and Seyewetz as being satisfactory. A fixing bath should be considered as exhausted (as a single bath or as the second bath in the

two-stage method) when a drop of it, placed on blotting or filter paper, turns brown on exposure for some time to moist air and sunlight.

Lastly, a more direct method (Bayer, 1921) is to withdraw 100 ml of the bath and to add to this quantity of solution 10 ml of a 4 per cent solution of potassium iodide; the bath may be considered as exhausted, so far as the single-solution method is concerned, when a permanent yellow precipitate is formed.

In an industrial installation, the silver content of the fixing baths is best determined colorimetrically by precipitating colloidal silver sulphide. The estimation is made using a photo-electric absorptiometer (W. J. Weyerts and K. C. D. Hickman, 1935). The estimation as silver selenide has been described by M. Abribat (1936).

In a professional installation, the silver content of the baths can be estimated approximately by dipping into the solutions test-papers coated with zinc or cadmium sulphide in gelatine. The brown tint obtained is compared with control papers that have been immersed in solutions of known silver content and then preserved, wet, in transparent sachets (H. Arens and H. Berger, 1937).

The silver content of the fixing baths should not exceed 4 g per litre for negatives, and 1.5 g per litre for papers. When continuous electrolytic regeneration of the fixer is applied the concentrations should be kept, respectively, to 1.5 g and 0.5 g per litre.

499. Preparation of Fixing Baths. Workers cannot be too strongly recommended to mix correctly the substances used in the preparation of fixing baths. These solutions are sufficiently stable to allow of being prepared beforehand in fairly large quantities. In order to reduce the bulk due to large quantities of stock solution it is a simple matter to prepare the actual baths when needed for use from more concentrated solutions.

We have seen (§ 495) that a very cold or very concentrated solution fixes very slowly, and also that a newly prepared solution of hyposulphite is very cold (§ 489); it is therefore not surprising that a fixing bath prepared just before it is needed by throwing haphazardly, and often liberally, some handfuls of hyposulphite into a dish of water, does not fix. If, weary with waiting for fixation to be completed, one throws the negative into a dish of water, fixation will be very rapid, but in the absence of excess of thio-sulphate it will not be complete.

The presence of particles of rust in the water used for preparing solutions (water distributed in iron pipes), or in the hypo (stored in sheet-iron containers), may cause solution of the silver in the image at the points where these particles settle, the iron oxide being slowly converted into ferric bromide by contact with the bromide dissolved in a partly-used fixing bath. (W. F. A. Ermen, 1923).

"Neutral" Fixers. "Neutral" fixers, comprising a plain 25 per cent solution of hydrated sodium thiosulphate (pH about 9) are only infrequently used.

Non-hardening Acid Fixers. A fixer rendered acid only by the addition of sodium bisulphite (pH about 5 increasing to 6, on exposing the fixer to the atmosphere, as sulphur dioxide is given off) is very rapidly neutralized by the alkali carried over from the developer, especially when no rinse is given. Such a fixing bath should only be used after a stop bath, under which circumstances some sodium sulphite should be added to protect the hypo from the action of the acid carried over.

Sodium thiosulphate (hydrated)	250 g
Sodium sulphite (anhydrous)	10 g
Sodium bisulphite	25 g
Water to make	1 litre

Acid Hardening Fixer. The following fixer (H. D. Russell and J. I. Crabtree, 1933) has the advantage of retaining its hardening properties over a greater range of pH than other hardening fixers do. When fresh, the pH is nearly 4.5.

The sodium thiosulphate is first dissolved in about 300 ml of water. The other ingredients, dissolved separately in small quantities of water, are added in the order given.

	Fixing bath	Acidifying Solution
Sodium thiosulphate, hydrated	300 g	—
Sodium sulphite, anhydrous	15 g	30 g
Acetic acid, glacial	10 ml	20 ml
Boric acid, crystalline	7.5 g	15 g
Potassium aluminium sulphate (alum)	15 g	30 g
Water to make	1 litre	1 litre

The re-acidification of this fixing bath under the conditions described in § 503 below, is best carried out using the above solution.

500. Fixation in Practice. Inasmuch as the ill effects of faulty working are not immediately evident, fixation and the washing processes which precede and follow it are not always carried out so carefully as is the case with development.

It is essential to realize that no visible sign

shows that fixation is perfect; a negative may be quite clear after fixing and drying and yet may not be properly fixed; it may not have been allowed to remain long enough in the fixer, or the fixing bath itself may have been exhausted. Images (negatives or positive prints) which are required to be kept for a long time must be fixed in a manner which conforms minutely to the following directions; these directions are much less important in the case of images which have merely passing interest.

501. The negatives, after being rinsed free of developer (§ 451), are placed in one of the fixing baths already prescribed, generally an acid fixing bath, or, in warm weather, in a fixing-hardening bath compounded with alum.

A safelight should be used, at any rate when putting materials in the fixer; in the case of neutral fixing solutions, negatives should be allowed to remain in the bath for at least three minutes before being exposed to white light; this period may, if necessary, be reduced to one minute in the case of acid fixing baths.

On account of the injurious action of the least trace of thiosulphate on certain developers, the various dishes employed must be so arranged that no splashes or drops of it can fall into the developer. The fingers should be rinsed in water after every time they have come into contact with hypo.

It will be found best to arrange dishes in the order in which they are to be used, those containing fixing solutions being placed at a lower level than those in which development is carried out. No drops of hypo solution must be allowed to fall on the floor, etc., for on drying, these would give rise to dust of a very harmful nature towards negatives subsequently handled in the room. For the same reason those negatives which in course of treatment are found to be useless should be at least rinsed before being thrown away.

Fixation being generally slower than development, it is advisable, in the case of continuous working, to provide larger dishes or tanks for this purpose than for development. For example, when working with dishes, one would use for fixation those of a size capable of taking two or four of the negatives under treatment.

During fixation, negatives must be well covered by the solution.

After some minutes in the fixing bath, an examination of the back of the negative shows that the milky coating of the silver halides under the developed image is beginning to dissolve,

the disappearance of the milkiness occurring as a rule more quickly under the denser parts of the image where least silver bromide remains.

From the time when the last traces of milkiness have disappeared the negatives are kept in the bath for a time equal to that already taken, or, preferably, when two-bath fixation (§ 496) is employed, they are transferred to the fresh bath and allowed to remain there for an equal time. When fixation is complete, negatives are washed.

If fixation is effected by the single-bath method, the solution must be frequently renewed so as not to pass the safety limit. In case of doubt, any of the tests described earlier (§ 498) may be used. In a very acid bath ($pH < 4.0$) the total fixing time should be at least four times as long as the clearing time (J. I. Crabtree, G. T. Eaton, and L. E. Muehler, 1943).

502. **Fixer for Materials rich in Silver Iodide.** Emulsions which have been more or less completely iodized (§§ 451 and 485) fix very slowly in a fresh fixer of normal composition. Fixing can be accelerated by adding ammonium chloride, or sulphate (or, for industrial use, potassium cyanide) to a solution of sodium thiosulphate.

On adding 4 per cent of thiourea (thiocarbamide) to a 20 per cent solution of sodium thiosulphate, the fixing time of a silver iodide emulsion is reduced from about 35 minutes to 3 minutes (J. Rzymkowski, 1926). The fixing bath should be sufficiently acid to avoid the formation of silver sulphide that would take place in the presence of alkali carried over from the developer. The fixer should be compounded as follows: 58 g of crystalline borax are dissolved in about 800 ml of water. A few drops of an alcoholic solution of methyl red are added, then about 18.6 ml of glacial acetic acid until a bright yellow tint is obtained ($pH = 6.4$); 200 g of sodium thiosulphate (hydrated) and 40 g of thiourea are dissolved in turn in the acid solution. The volume is then made up to 1 litre.

After being fixed in the thiourea bath, the material should be further treated in a plain, or slightly acid hypo solution, otherwise a dense white opalescence will be produced in the emulsion when it is washed.

Silver iodide emulsions can also be fixed in a 40 per cent hypo solution at 30°C. As a result of the high hypo concentration, the gelatine is unharmed (Lüppo-Cramer, 1925).

503. Regeneration of Fixing Baths. The following items will be discussed—(a) the maintenance of constant acidity and (b) hardening power, (c) the electrolytic regeneration of fixing baths by removing the silver, the life of the bath then being limited by the concentration of soluble iodide that accumulates, (d) the elimination of soluble iodide, which is not much practised, but which leads to a more economical use of the hypo.

(a) *Maintaining the Acidity of a Non-hardening Fixer.* The acidity is progressively reduced when developer is carried into the bath by negatives that are not rinsed, or which are only briefly rinsed. On the other hand the acidity is increased when an acid stop-bath is used between the development and fixation.

Sulphite is formed when the bisulphite in the fixer is neutralized by alkali, and the bisulphite can be regenerated by the cautious addition of dilute sulphuric acid. This operation should only be carried out by a chemist because an excess of sulphuric acid will cause the decomposition of the thiosulphate. For this reason it is usually preferable to re-acidify the bath by adding sodium bisulphite in concentrated solution. Each time the pH of the bath rises above 6.5, as shown by the change from yellow to blue of bromthymol blue indicator, a quantity of bisulphite should be added equal to half the quantity used when making up the fresh bath. The indicator solution can be prepared by dissolving 0.4 g of bromthymol blue in 75 ml of a 0.05 per cent solution of sodium hydroxide and then diluting to 1 litre with distilled water. Other indicators, mentioned below, are prepared in the same way.

The carry-over of a very acid stop-bath solution into the fixer may result in the decomposition of the sodium thiosulphate (hypo). Under these conditions it is necessary to prevent the pH from falling below 4.0 as shown by the change of the colour of bromphenol blue indicator from blue to yellow. This can be accomplished by adding sulphite and, if necessary, a small amount of sodium carbonate.

When a chrome-alum stop-bath is used, it is especially necessary to ensure that the pH of the fixer is not greater than 6.5 because a pH value greater than this may cause the precipitation of chromium hydroxide on the emulsion.

(b) *Maintaining the Acidity of a Hardening Fixer.* Hardening fixers which contain alum, and which are stabilized with boric acid, retain their hardening properties over a wide range (4.5 to

6.3) of pH. They can, therefore, be used without re-acidification to fix a larger area of negative emulsion than ordinary fixers can. Such fixers take (per litre) as much as 100 ft of 35-mm film before requiring re-acidification, whereas a fixer employing only acetic acid needs re-acidifying after 12 ft of film. When no electrolytic recovery of silver is employed, a boric-acid fixer can be exhausted to the extent of two or three re-acidifications. The bath should be re-acidified when 1 ml of bromcresol purple indicator added to 10 ml of the bath shows a reddish colour (pH = 5.6). It shows a yellow colour in the fresh fixing solution.

At each re-acidification, about 7.5 ml of acetic acid per litre are added, after the acid has been diluted with about 70 ml of water. The fixing-bath is vigorously stirred while the diluted acid is added.

(c) *Electrolytic Regeneration of Fixing Baths.* Several of the chemical processes for the recovery of the silver from used fixing baths can be used to regenerate the bath providing that the quantity of reagent used is insufficient to precipitate all the silver. These processes have been replaced, in industry, by the electrolytic deposition of the silver from the fixing bath in current use, the silver content of the bath always being maintained at a very low level, and the bath is only rejected when the increased concentration of iodide makes the fixing rate become slow. It has been suggested (P. Strauss, 1925) that the poisoning effect of the iodide could be offset, under these conditions, by adding a small quantity of sodium cyanide to the bath.

The electrolytic regeneration of fixing-baths, suggested by W. M. Schultz (1928) and by F. E. Garbutt and T. M. Ingman (1929) has been very thoroughly studied by K. C. D. Hickman and W. J. Weyerts (1931).

In the electrolytic separation of the metal from the aqueous solution of a simple salt, the metal ion travels towards the cathode (the negative electrode) where it is discharged and becomes an atom of the metal. The acid ion (anion) travels to the anode which it attacks, or it liberates oxygen by reacting with water. In the electrolysis of the complex salt, sodium argentothiosulphate, sodium ions migrate to the cathode and argentothiosulphate ions move towards the anode. The sodium atoms formed at the cathode react with neighbouring ions in solutions, including the argentothiosulphate ions. If there are sufficient argentothiosulphate

ions, the sodium atoms react with these, liberating silver. In the absence of these ions the sodium reacts with the thiosulphate (hypo) ions giving, among other things, sulphide ions which, in turn, react with argentothiosulphate ions to form silver sulphide, discolouring the solution.

Thus it will be seen that the metallic silver is produced by a *secondary reaction* on ions which are tending to move away from the electrode on which the metal is deposited. In order to ensure a sufficient concentration of argentothiosulphate ions at the cathode it is necessary either to stir the solution very vigorously so that high current densities may be used, or to limit the current density to a few milliamperes per square decimetre (H. G. Doffin, 1935). The second course would occasion the use of a very large electrode surface in order to achieve an industrially practicable rate of recovery.

In order to recover 1 g of silver, without any loss of current, it would be necessary to use 0.33 ampere-hours.

The anodes employed are always of graphite, and while the cathodes may be also of graphite, stainless steel is usually preferred.

The electrolytic deposition of silver, without the formation of sulphite, is practicable only in an acid bath. The maximum current density that can be used, while obtaining a smooth, shiny deposit, increases, within certain limits, with the degree of agitation, the temperature, the silver content, the acidity, and the sulphite concentration. It decreases as the bromide ion concentration is increased.

With a degree of agitation sufficient to produce a solution velocity of 30 centimetres per second relative to the electrodes, a current density of 0.15 ampere per square decimetre of cathode may be used in a bath containing 1 g of silver per litre. The current density can be increased to 0.5 ampere per square decimetre if the solution velocity relative to the electrodes reaches 75 centimetres per second or, without increasing the agitation, to 0.9 ampere per square decimetre if the silver concentration is 6 g per litre.

At low current densities the silver deposit is white. On raising the current density, the deposit becomes cream, then yellow, and finally dark brown with the formation of a silver sulphide sludge. If this stage is reached, it is necessary to empty and thoroughly clean the installation.

When the silver deposit reaches a thickness of 0.5 millimetre it often acquires a coarse crystal-

line structure. The immobilization of the solution in the crevices makes it necessary to reduce the current density in order to avoid the formation of silver sulphide. The presence of gelatine and its degradation products in the used fixers favours the formation of a brilliant deposit. However, in the usual concentration, it has an adverse effect on the process, in that the gelatine is attracted towards the cathodes where it is to some extent deposited with the silver, forming a layer of high viscosity around the electrode and thus hindering the access of argentothiosulphate ions to the cathode. This difficulty can be overcome by the addition of thiourea.

Because the perfect clarity of the bath is necessary, as well as agitation, it is necessary to filter it before, as well as during, the electrolysis, otherwise the suspended particles may lead to pitting of the silver deposit with the consequent formation of silver sulphide.

When continuously regenerating the fixing bath, it is necessary to reject part from time to time, replacing it with suitably compounded, fresh solution. An industrial installation should thus include cells in which the silver content of the circulating bath is kept between 0.5 and 1.0 g per litre and at least one "tailing" cell in which the silver is entirely removed, the contents of the cell being then rejected.

The good operation of such an installation consists in the close control over the current density, though means have been suggested by K. C. D. Hickman for automatically estimating the silver content and adjusting the current density.

(d) *The Elimination and Recovery of the Iodide from Fixers.* The fact that the life of a regenerated fixing bath is limited by the accumulation of iodide, and the comparatively high price of iodine, make the recovery of the iodide a practical proposition at least in an industrial establishment (K. Kieser, 1934-7). A 5 per cent (saturated) solution of thallous sulphate (*poisonous*) is added to the bath. The first additions precipitate yellow-orange thallous iodide which soon settled to the bottom of the vessel. The additions are continued until light-yellow thallous bromide is predominantly formed. The thallous bromide is converted to the iodide by adding it to the next batch of fixer to be treated before making additions of thallous sulphate. On an average, the sodium iodide content of an exhausted fixer is about 0.4 g per litre.

After washing it with water, the thallous iodide is reconverted to thallous sulphate by warming with concentrated sulphuric acid to liberate the iodine.

504. Recovery of Silver from Exhausted Fixing Solutions without Regenerating the Bath. On the average, about three-quarters of the silver contained in sensitive materials pass into the fixing baths. Negatives contain about 10 g and papers about 2 g of pure silver per square metre. A litre of exhausted fixer usually contains 4 to 5 g of silver, or from 10 to 12 g of silver when it is the first of two successive fixing baths. Assuming that the necessarily imperfect process of recovery in a small works only permits of a yield of 75 per cent of these quantities, one can estimate the value of this recovery, allowing for the cost of precipitation (never very high) and for the cost of extracting the silver by the smelters.

The silver in fixing baths is generally precipitated in the form of sulphide. Under these conditions, and provided that the silver is not completely precipitated, fixing baths may be used again, at least once, though not indefinitely, because the accumulation of soluble bromides and particularly of iodides in the solution considerably retards fixation in solutions so regenerated.

The silver may also be recovered in the metallic state by precipitation on plates or scraps of zinc, iron, or copper. In this case the silver is contaminated with various impurities and needs to be refined.

To the residues thus collected are added the ashes of clippings from prints and films stripped from waste negatives.

505. When the silver is precipitated as sulphide, the exhausted baths must be stored and treated in a yard or shed which is far enough from darkrooms, store-rooms, etc., to avoid any risk of sulphuretted hydrogen coming in contact with sensitive material.

The used fixing baths are thrown into a barrel having wooden hoops and with the top removed. This barrel should be mounted on bricks; it must be provided at about a quarter of the way from the bottom with a wooden outlet or tap, so that the greater part of the liquid may be run off, and at the bottom with a bung-hole, from which the sludge of silver sulphide may be periodically run off. Old developing solutions may also be poured into the same vessel, since they contain a little silver. These solutions will reduce a small quantity of

the silver in the fixing solutions to the metallic state, and they will also tend to neutralize the residual acidity of the fixing baths. When the barrel is about three-quarters full, about 45 g of sodium sulphide is added for every gallon of liquid to be treated (10 g of the sulphide for every litre of liquid). This sulphide should be previously dissolved in a little boiling water. The mixture is stirred with a stick and left to settle. The next day a little of the clear supernatant liquid is taken in a test-tube (if the liquid is turbid it must be filtered) and a few drops of a solution of sodium sulphide are added; if no black precipitate forms, the silver has been completely precipitated; if, on the contrary, a black precipitate forms, add to the liquid in the barrel about half as much of the sodium sulphide as before and repeat this process if necessary until all the silver has been precipitated. After a final settling, the liquid is run off by the tap through a filter-bag of close felt placed so as to trap any silver sulphide which might be lost.

After the cask has been emptied in this way several times, as successive lots of fixing bath are treated, the black sludge is run off through the lower bung-hole and is collected in a tray. After drying, this mud is stored in a box until a sufficient quantity has been collected for sending to the smelter.

Pure dry silver sulphide contains 87 per cent of its weight of fine silver. On account of numerous impurities which accompany it, silver sulphide obtained in the manner described works out at about 60 per cent if it is precipitated from baths free from alum, and at about 40 per cent when it is contaminated with alumina or chromium hydroxide resulting from the interaction of sulphide with alums.

506. To recover the silver from old fixing solutions by another method, a barrel of 5 to 10 gallons capacity, and equipped as in the previous case, may be used. Before starting the recovery process, the liquid must be neutralized, by means of sodium hydroxide (caustic soda) or milk of lime (lime first wetted with a little water and then left to slake) if it reddens blue litmus paper, or with sulphuric acid if it turns red litmus blue; at the neutral point practically no change of colour takes place with either kind of paper. Then the liquid is acidified by adding 100 ml of ordinary sulphuric acid (66° Baumé). After stirring, about 1 kg of granulated or scrap zinc for every gallon of liquid (200 g per litre) are thrown into the barrel; this quantity

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causes rapid precipitation (in about 24 hours, if the mixture is stirred from time to time) of silver (partially in the form of sulphide), which forms a black deposit on the zinc and in the bottom of the barrel.

An appreciable economy of zinc may be effected by enclosing the latter in a bag of coarse cloth suspended in the liquid.

On the next day, in order to find whether or not the liquid still contains any dissolved silver, proceed as follows. In a test-tube take a little of the clear, reddish, supernatant liquid, acidify with a few drops of sulphuric acid, shake (make sure that the liquid reddens blue litmus paper), and add about one-fifth of its volume of a 10 per cent solution of sodium sulphide; if no black precipitate forms, the silver is completely precipitated (a black precipitate obtained without the liquid being acidified has no significance);

if silver still is present, keep the zinc in contact with the liquid for another day. As soon as all the silver is deposited, decant the liquid by the side opening.

One charge of zinc suffices for seven or eight such recovery processes without any appreciable slowing of the action. When the precipitation needs from two to three days, it may be accelerated by adding about 85 g of zinc per gallon of liquid (20 g per litre). Under these conditions, 1 g of zinc allows of the recovery of about 1 g of silver.

From time to time the black deposit is collected and dried.

These various operations should be carried out in a well-ventilated place, as far as is convenient from darkrooms and any sensitive materials. As well as zinc, copper turnings, and iron, in the form of steel wool, can be used to recover the silver.

CHAPTER XXX

WASHING

507. The Function of Washing. Photographic materials are washed to remove all the soluble salts formed during fixation, also the constituents of the fixing bath which may be absorbed in the emulsion layer or adhering superficially to the prints or negatives.

According to circumstances, it may be necessary to carry out the washing either in the minimum time or with the minimum quantity of water.

If fixation is complete, so that the emulsion contains nothing but the silver of the image and soluble salts, then the salts are readily washed out, provided the washing is systematic. If fixation is incomplete, the remaining insoluble salts cannot be eliminated, no matter how long the washing is continued. It is probably with a view to establishing a mean between these two experimental facts that photographers generally state the "hypo is strongly retained by gelatine." This is true of the insoluble thiosulphates which result from bad fixation, but it is not so for the soluble salts, which are the only ones remaining after complete fixation.

This chapter will deal with the following subjects: (a) The mechanism of washing in changes of water and in running water, and it will be shown that washing in running water in the manner generally employed is a means of consuming the greatest amount of water with the smallest effect. (b) The conditions which must be fulfilled in order to wash negatives or prints in the most rational manner. (c) The use of *hypo-eliminators*, from which it will be seen that there is only one perfect eliminator applicable to all cases, viz. plain water.

It may be useful to re-state here an evident truth: an object cannot be cleaner, after washing and drying, than the water used for washing it.

508. The Mechanism of Washing in Several Changes of Water. Thorough investigations of washing in successive baths were made by A. V. Elsdon and A. W. Warwick (1919). The methods followed by these two experimenters were almost identical. Plates or films, developed or undeveloped, were fixed in baths of known strength. They were then successively placed into accurately measured quantities of water for known periods of time. The quantities of

thiosulphate and soluble silver in each of these washing waters were determined. Finally, after completing the washings, the amount of thiosulphate remaining in the film was also determined.

These experiments, and many others (Haddon and Grundy, 1893-96; Gaedicke, 1897; Lumière and Seyewetz, 1902), established the fact that, the elimination of soluble thiosulphates by washing with water is easily carried out; this is in accordance with the general law of the diffusion of ions through permeable membranes. It is necessary to wash photographic materials on a paper base for a considerably greater time than those on a glass or celluloid base, as the paper tends to retain the thiosulphates. The thiosulphates are automatically expelled from the gelatine providing their concentration in the liquid in which the material is washed. If a film of gelatine, impregnated with fixing solution of normal concentration, is placed in pure water at a temperature of about 60°F, the "osmotic pressure" of the thiosulphate, that is to say the pressure which the salt exerts in leaving the gelatine, is considerably greater than 5 lb per square inch.

As soon as a negative, impregnated with any salt which does not react with gelatine (as does alum, for example), is placed in pure water, the salt in the solution adhering superficially to the negative becomes distributed in the water, and the salt absorbed in the gelatine diffuses out, at first very quickly and then more and more slowly, until finally the concentrations in the gelatine and the water are equal.

If the negative has been placed at the bottom of a dish or tank full of still water, the salt solution which diffuses out of the negative, and which is denser than the water, accumulates above the plate; this solution soon becomes equal in concentration to the solution which impregnates the gelatine. The movement of salt is then arrested, since the uniform diffusion of the salt throughout the liquid in the tank takes a very considerable time. If, however, the water is stirred mechanically, or if the negative is placed so that the salt solution can leave it and be replaced by pure water, the diffusion

proceeds much farther, each separate washing having a much greater effect. This is the case if the negative is supported emulsion downwards in the upper part of the tank, or is placed vertically in the tank with a sufficient depth of water below it to allow for the accumulation of the denser solution.

When a 13×18 cm (7×5 in.) plate is removed from a fixing solution it takes with it about 5 ml of solution (the total liquid adhering superficially to the plate and impregnating the emulsion). If the fixing bath contains 20 per cent of hypo the plate will have removed 1 g of it from the bath. If now the plate be placed in a dish containing 95 ml of water, the total volume of liquid will be 100 ml. By rocking the dish, equilibrium will be attained between the internal and external concentrations of hypo, which will become 1 per cent, that is to say, a concentration of one-twentieth the initial concentration. By repeating this process, the concentration becomes one-twentieth the previous concentration, and so on—

Number of washings	1	2	3	4	5
Concentration %	0.05	0.0025	0.000125	0.000006	

It can be assumed (K. Hickman and D. A. Spencer, 1922) that a residual amount of hypo equal to 0.0016 g per square decimetre has no adverse influence on the permanence of silver images. By taking a quantity ten times as small (to ensure absolute safety), viz. 0.00016 g per square decimetre, or 0.00036 g for a 13×18 cm plate, it will be seen that if this quantity is regarded as being distributed in 3 ml, which is approximately the volume of water absorbed by the emulsion, the washing may be considered effective as soon as the concentration in the washing water has been reduced to $0.00036 \times 100/3$, or about 0.01 per cent. This stage will be reached after a very small number of separate washings, provided each one is carried out to completion in a sufficient volume of water.

Equilibrium between the concentrations inside and outside the gelatine is generally reached after 5 minutes' rocking of the dish, but 99 per cent of the amount, which will diffuse from the gelatine has usually come out in about 2 minutes. It is thus seen that, for rapid washing, each separate washing need not be longer than 2 minutes provided sufficient agitation is used.

As a general rule, when washing, it is not essential to rock the dish or to wait until equilibrium has been reached: it is only when the amount of water available is restricted that these considerations become important, and

then special methods are employed (§ 512). In general, then, each washing withdraws only a fraction of the amount of hypo which could be removed if equilibrium were attained, and this fraction, which varies according to the mode of working, is to some extent a measure of the effectiveness of the washing. It was shown that washing is more effective if the negatives are held vertically than if they are placed emulsion upwards at the bottom of the tank; the efficiency can be still further increased if the surface liquid is allowed to drain from the negatives before transferring them to the clean bath.

Most experimenters agree that there is nothing to be gained by prolonging the duration of each washing beyond 5 minutes, and that if 15 ml of water per square inch of emulsion is used, 5 or 6 washings are quite sufficient to ensure that the permanence of negatives on film or glass supports will be as great as the efficiency of the fixation permits.

509. The Mechanism of Washing in Running Water. Washing tanks are frequently so badly adapted to the object in view that the water flows directly from the tap to the sink without flowing *through* the tank, and therefore does not remove more than an extremely small proportion of the hypo which it should remove. The effectiveness of washing depends neither on the amount of water used nor on the time during which the water flows, but on the volume of water which comes into effective contact with the plate and on the rapidity with which the water charged with hypo is replaced by fresh water. Unless a scientifically constructed apparatus which permits the frequent renewal of the water in contact with the negatives is employed, running-water washing is slower than washing in separate changes of water, its only advantage being an economy in labour.

The proportional reduction in concentration of the liquid in the emulsion, in a fixed period of time, will always be in the same ratio providing the washing conditions remain constant. The magnitude of this ratio, which is to some extent a measure of the effectiveness of a washing apparatus varies from one apparatus to another.

The best method of washing a single plate in running water is to allow water to flow directly across the plate (this method is not applicable to papers or films); the elimination of hypo is then about twice as fast as it is when the plate is placed in a washing tank through which water passes much more violently.

The worst conditions are obtained by using a

large dish, or a tank without an outlet at the bottom, and a thin stream of water. Then, owing to the presence of eddies in the water, the speed of washing varies considerably from one part to another.

Experience shows that in the case of a tank, with vertical grooves for the plates and fed by a constant stream of water which is removed by a siphon, the elimination of hypo is more rapid when the tank is fully loaded with plates; it would seem that when there are no plates in the tank the incoming water dilutes the salt solution instead of displacing it.

The very accurate work of Hickman and Spencer (1922-25), to whose work we are indebted for much of the data in this paragraph, has shown that washing in running water may be considered as taking place in two stages: the total replacement of the water in the tank, and the attainment of equilibrium between the liquid in the emulsion and the water in the tank. The time necessary for equilibrium varies, according to the type of plate or film used, from 5 to 10 minutes; obviously no time can be set down for the complete renewal of the water in the tank, but it often requires more than an hour. It is easy to determine experimentally the time required for this phase of washing, by the following method.

Place in the dish or tank (in the case of a vertical tank, the place normally occupied by plates to be washed should be filled with plain glass) about 2 ml of a 2 per cent solution of safranine, or of a saturated solution of permanganate (permanganate solution should be employed only in tanks constructed of glass, earthenware, or slate; safranine only should be used with tanks of wood or metal) for each square inch of surface to be washed (25 ml for a $4\frac{1}{2} \times 3\frac{1}{2}$ in. plate). The time is noted, under normal conditions of washing, for the water in the tank to become completely decolorized. The end-point can be judged by comparing water from the tank and pure water, using two identical glass vessels against a white ground for the purpose.

If, for example, it is usual to use six $4\frac{1}{2} \times 3\frac{1}{2}$ in. plates, then about 150 ml of the coloured solution would be required. If an interval of 35 minutes is necessary for complete decolorization of the solution, then for normal washing with the same water supply the time should be 35 minutes plus the 10 minutes necessary for obtaining equilibrium between the solution in the gelatine and that in the tank; the washing

time, therefore, under the conditions of the test, will be 45 minutes.

Since the gelatine backing of films holds as much hypo as the emulsion, their area must be doubled in order to calculate the amount of coloured liquid required for the test. The back of a film should be washed as carefully as the front; the spots of silver sulphide, arising from the decomposition of the silver hyposulphite absorbed in the fixing bath, are liable to occur also on the back.

510. Apparatus for Washing. The washing of a small number of plates is frequently carried out in dishes, but for continuous work vertical tanks (tanks with grooves, or tanks, without grooves, into which the plates are placed in developing racks) are generally preferred. To ensure efficient washing it is essential that the tank be effectively traversed by the current of water. For this, two arrangements are used concurrently; water can be led in at the bottom of the tank and out over the top or through an overflow pipe, or it can flow directly from the tap into the tank and then out through a tube which communicates with the bottom of the tank and empties at a level slightly lower than the rim of the tank. The type of tank commonly used by amateurs, viz. one with an outlet only in the bottom, can easily be converted by fitting to the tap a rubber tube which is tied to the tank by string; or by soldering to the interior of the outlet a lead tube bent into the form of a swan's neck.

Various washing devices are available in which the water is kept in turbulent movement either by entering through obliquely-set nozzles, or by the plates or films being mounted on a drum which is kept rotating by a very simple water motor (paddle-wheel or simple turbine).

As it has long been realized that washing in running water is slower than washing in changes of water, many inventors have attempted to construct an automatic apparatus for changing the water so that the handling, which is the only objection to this method of washing, may be eliminated. These machines are usually either tanks operated by a large emptying siphon, which is self-priming directly the tank is full, as with the tantalus cup, or ordinary tanks fed intermittently from a flush tank, or tanks with automatic flushing controlled by the outlet plug, or finally, for small sizes of plates, dishes which empty by tilting when full, and then immediately return to the filling position under the tap.

For economy in water, several washing tanks are sometimes arranged in *cascade form*; it is then necessary to place the plates to be washed in the lowest tank first and then to transfer them successively from tank to tank, so that the final washing takes place in the upper tank containing pure water. Unless this counter-current movement of the plates is adhered to, plates in the lowest tank will not be in contact with water of a sufficient purity and hence will not be completely washed until after the washing of all the other plates in the tanks higher up in the series.

To ensure that the washing is done under the best possible conditions, the tanks should be smooth inside and should not be larger than necessary; a plate can be washed more quickly in a small than in a large tank.

511. Control of Washing. Since the completion of the washing process is not accompanied by any indication that all the salts have been eliminated, various methods have been suggested for ascertaining when washing is complete.

It is possible, for example, to discover that the water which drips from a plate or print does not contain enough hypo to be detected by the usual methods, i.e. does not decolorize a starch solution which has been made blue with a trace of iodine, or a solution of permanganate, both solutions having been made of a suitable strength.

Dissolve 1 g of potassium permanganate and 1 to 2 g of sodium carbonate in 1 litre of water. This solution has an intense violet colour. Collect the drainings from several plates or prints in one glass vessel, and an equal quantity of the water used for washing (taken straight from the tap) in another. Add to each one drop of the above permanganate solution. If the colour persists in the drainings for as long as it does in the fresh water, the washing may be considered to be complete.

Should the single drop of permanganate be instantly decolorized by the water used in the blank test (owing to the presence of organic matter), further drops should be added until a permanent pink colour has been obtained. The same number of drops should be added to the drainings.

A much more sensitive reaction, in which the traces of thiosulphate catalyze the discoloration by sodium nitride (NaN_3) of the iodine coloured by starch, has been described by E. E. Jelley and W. Clark (1929), but its application is more delicate.

Finally, attention should be drawn to a check method invaluable in experimental work, but the practical use of which is restricted as it involves the loss of the images tested and is therefore suitable only for cinematographic films of which it is always possible to cut off a strip of a few inches. Pour into a test-tube 10 ml of a solution containing 25 g mercuric chloride and 25 g of potassium bromide per litre. Then put in 10-15 sq cm of image (film, or layer of emulsion scraped off a plate). The liquid becomes opalescent when thiosulphate is present; the concentration can be ascertained by comparison with samples prepared with known quantities of thiosulphate (J. I. Crabtree and F. E. Ross, 1930).

In commercial establishments the control of washing may be effected by comparing the electrical conductivities of the feed and waste waters of the tanks (K. C. D. Hickman, 1923).

These tests are very good in their way, but it is essential that their exact significance be understood. The fact of finding no hyposulphite in the drippings certainly indicates that the soluble hyposulphites have been removed and that, as a consequence, the washing is complete. But it gives no information as to the completeness of the fixation, and hence of the permanence of the image, the test giving no indication of insoluble complex thiosulphate of silver and sodium which may be in the film. This control of fixation may be made, after washing, by placing on the clear part of a plate or print a drop of a 10 per cent solution of sodium sulphide. If fixation is not complete, a brown spot, more or less dark, will appear. As a spot of this sort is indelible, it is obvious that the test is applicable only to waste plates or papers, unless the material is deliberately sacrificed for the purpose of the test.

512. Washing in Practice. As far as the amateur photographer is concerned, the choice between washing in running water and washing in changes of water will be settled by personal convenience; for the professional, or on the industrial scale, the choice will depend on the relative costs of water and manual labour.

It must be remembered that washing in running water is less effective when it is carried out in baths of large size, and that the hypo should be removed from the tank directly it diffuses out of the emulsion. It may be said that on the average the first seven minutes are taken up with washing the plates and the rest of the time with washing the tank (Hickman, 1925). It is therefore

necessary to use tanks of suitable size and design so that the washing of the tank is almost as rapid as that of the negatives.

In a case of extreme urgency, water may be allowed to flow directly over the plate to be washed, or three successive washings each of 2 minutes may be given, but plenty of water must be used and the dish must be rocked continuously for the whole period; the interrupted washing should be subsequently completed.

In ordinary work, when washing in changes of water, five or six washings of about 5 minutes each in plenty of water are given. With running water, at least an hour should be allowed when using a tank which is effectively flushed with a rapid current of water; or, better, the time required for complete washing should be determined for the particular tank with a given consumption of water (§ 511).

When the supply of water is very limited, the best results are obtained by employing for each washing only just enough water to cover the plates, draining the plates between each washing and increasing slightly the number of washings. For washing in running water the *capillary flow method* (L. Lumière, 1922) may be used. The complete washing of a plate $4\frac{1}{2} \times 3\frac{1}{2}$ in. may thus be done in 12 to 15 minutes with only about 30 ml. of water. For this purpose, the slow and regular capillary flow of water in an almost vertical ribbon of cotton twill is used. The water is fed from above by a tank, from which, so to speak, it is siphoned; the plate is placed on the twill, which has been previously wetted, care being taken to avoid air bells. The flow of water may be regulated by the height of the fall measured from the level of the water in the reservoir to the free end of the ribbon.

Plates and prints can be washed in sea-water, except that at least two washes in soft water are necessary to remove the salts of the sea-water, and particularly the deliquescent magnesium chloride. The use of distilled water or of slightly acid water does not result in the complete elimination of hypo owing to the impossibility of converting the "gelatine thiosulphate" formed during fixation in the acid fixing bath, into "calcium gelatinate."

When a plate is taken from the fixing bath and placed in the washing-tank, the concentrated fixing salt diffuses out from the emulsion and is partly absorbed by any other negatives in the tank which may have been partially washed. Therefore whenever plates are introduced one after the other into a bath to be

washed together, the time of washing or the number of changes of water must be counted *from the insertion of the last negative*.

In the case of films or prints left to themselves in a dish or tank, washing in running water is liable to be ineffective if the surfaces to be washed cover each other and thus afford mutual protection against free contact with the current of water. Washing in several changes of water is therefore the only possible way, but the films or prints must not settle in a stationary heap at the bottom of the dish but must be kept moving. This can be done by making two piles in the dish and transferring the prints or films one by one from one heap to the other: also by transferring them singly from one tank to another.

Contradictory opinions have been expressed on many occasions regarding various circumstances which are capable of affecting the speed of washing. It has been stated, for example, that the washing of plates which have been fixed in an acid bath is slower than the washing of plates fixed in a neutral bath, when, on the contrary, the swelling of the gelatine in a neutral bath prolongs washing considerably. It is often stated that washing is accelerated by increasing the temperature of the water but many experiments show that the speed of washing is independent of the temperature of the bath (more rapid diffusion is compensated by the swelling of the gelatine in the warmer water). It has also been stated that washing is retarded by the use of alum in the fixing-bath but experiments have shown that alum added to the fixing bath does not retard the changes in the interior of the emulsion unless in the interval the emulsion has been dried (Eastman Kodak Laboratories, 1921). If the alum treatment were carried out in a neutral solution as a separate operation, the result would be the same.

If, in certain circumstances, it is necessary to keep a plate in water for an unusually long time, it is advisable to add (to the water) a little sodium bisulphite (about 5 per cent) to stop the gelatine swelling excessively and thus becoming very tender. An emulsion, which has not been hardened with alum, if kept for a long time in polluted water is liable to be attacked by bacteria, which will cause liquefaction of the gelatine in patches. For this reason plates should never be left in water overnight.

When the only water available for washing contains a large quantity of chalk, which tends to form a superficial fog on drying, it is advisable,

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to ensure that the negatives shall have a perfectly clear surface, to follow the washing with a few minutes' immersion in a 1 per cent solution of hydrochloric or acetic acid. This precaution is particularly to be recommended for the very small negatives intended for large scale enlargement. In this case lime deposits, even imperceptible to the naked eye, increase graininess of the enlarged image. It is also advisable for all negatives when alcohol is used for rapid drying, since it avoids the formation of an opaque white fog, which would appear chiefly on those portions of the plate which had dried most rapidly (L. P. Clerc, 1917).

It is as well always to complete the washing of plates under a spray of perfectly filtered water, to free them from foreign bodies which may adhere to the gelatine during drying.

It is sometimes recommended that film negatives should be rinsed in water containing a little glycerine in order to give a greater suppleness to the dry film. But all photographic images which have been treated with glycerine remain permanently damp, and atmospheric action on the silver is thus facilitated; many cases have been cited of slow changes in images thus treated.

513. Hypo Eliminators. The idea of attempting to destroy hypo instead of eliminating it is almost as old as photography. This idea is unfortunately opposed to common sense, and to a sufficiently large number of experimental facts. To begin with, a chemical action never "destroys"; it can only transform; and those who have commended such practice have usually not tried to discover whether the products of this transformation are any less liable to damage the image than is the hypo from which they have been obtained. On the other hand, the substance which actively alters images is not so much the sodium thiosulphate as the insoluble complex thiosulphate of silver and sodium. It is therefore necessary to find out the form in which this salt of silver exists after the action of the eliminator.

All the substances which have been recommended as hypo eliminators are oxidizers; we may mention sodium hypochlorite (F. W. Hart, 1864), hydrogen peroxide (A. Smith, 1866), iodine (H. Vogel, 1872), potassium persulphate

(Schering, 1894), sodium hypiodite (P. Mercier, 1897), potassium percarbonate (G. Meyer, 1901), alkaline ammonium persulphate (Lumière and Seyewetz, 1902), alkaline perborates (G. F. Jaubert, 1903), and the sodium compound of p-toluene-chloro-amide-sulfonate (E. F. Shelberg, 1922), which, in aqueous solution, slowly decomposes to give hypochlorite.

As early as 1889, Traill Taylor stated that "if one wishes to take all the precautions which are necessary in order to apply the would-be hypo eliminators without danger to the photographic images, the operation will be found to be longer and more complicated than the washing itself."

Many experimenters who have studied the reactions involved in the oxidation of thiosulphates (notably Chapman Jones, 1899, and E. Sedlaczek, 1904) have shown that most of the oxidizers used attack the silver of the photographic image, and that in reacting with the thiosulphate they form tetrathionate and dithionate (as well as inert sulphate), which appear to be as dangerous to the image as is the thiosulphate itself; they also resemble thiosulphate in interfering with subsequent treatment, such as intensification.

Experiments made by A. E. Amor (1925) to determine the effectiveness of various eliminators, in which the residual hypo of plates at various stages of washing (with and without eliminator) was measured, show that the efficiency of oxidizers is less than that of a single washing in a 0.2 per cent solution of caustic soda, and that after one extra wash (the duration of each wash being 2 minutes) the elimination of hypo is more complete than it would be were an eliminator used for the same time, and much less risk of damage to the image is incurred.

Sodium hypochlorite is the most dangerous of all the eliminators, yet, in France, it is also the one most frequently employed. The resulting image contains silver chloride, which is liable to change on exposure to light, giving irregular violet-coloured patches; and, in fairly strong solution, sodium hypochlorite attacks both silver and gelatine.

The best method, then, is to leave these various reagents severely alone, and to use the only perfect eliminator, pure water, constantly applied to the surface to be washed.

CHAPTER XXXI

DRYING

514. The Purpose of Drying. Photographic plates and films which have been washed at temperatures between 60°F and 68°F, and have been wiped free of water clinging to the surface, contain an amount of water which is about six to ten times the weight of the gelatine in the emulsion, so that it may be as much as 0.05 to 0.15 ml of water per square inch of emulsion surface. In the case of films coated on the back with gelatine, an approximately equal quantity of water will be contained in this backing layer. The amount of water absorbed is considerably greater at higher temperatures.

In the process of drying, this water has to be evaporated without injury to the image (partial or complete melting, markings, reticulation, etc.); at the same time, the adhesion of dust to the moist emulsion must, as far as possible, be prevented.

Obviously, drying will be more rapid if superficial water is wiped off at the start.

It must be noted that even after long and effective washing, the water held by the negative still contains traces of sodium thiosulphate too small indeed to be detected even by the most delicate means. As drying proceeds, however, adhering water collects in drops, which grow smaller and smaller, so that the whole of the thiosulphate in this water becomes concentrated in small areas which may then show up as defects due to insufficient washing (K. C. D. Hickman, 1926).

515. The Physics of Drying. The air always contains a certain amount of water in the form of vapour, this quantity varying greatly according to circumstances. Comparatively dry air, when kept in the presence of water or moist bodies, or into which water vapour is introduced by a boiler, will take up moisture to a certain maximum, which increases according to the temperature of the air. When this limit has been reached, the air is said to be *saturated* with moisture. The ratio of the quantity of water vapour present in a given volume of air to the quantity which would be present in the same volume of saturated air is called the *hygrometric condition*, the *fraction of saturation*, or the *relative humidity*. On cooling the air, its relative humidity is increased, and it may become

saturated (condensation of mist or deposition of dew). Conversely, the relative humidity of air is decreased when the temperature is raised.

Air of 50 per cent relative humidity is considered as being very dry. In cold, damp weather the almost saturated outside air has its relative humidity lowered to 30 per cent or even less when it is warmed to the normal temperature of a workshop or dwelling house.

Dry gelatine absorbs water in a moist atmosphere, whilst moist gelatine loses moisture in a dry atmosphere. In saturated air, which is unable to take up any more moisture, all evaporation is prevented, and as a consequence moist gelatine cannot be dried in it, even though the amount of moisture to be removed be very small. The rate of drying is very nearly inversely proportional to the relative humidity of the air. Air which is warmed to reduce the relative humidity has its capacity for drying increased to a greater extent when the rise of temperature is large. The practical limits of drying by this system are, however, quickly reached because of the risk of melting the gelatine. Since the air becomes loaded with moisture as evaporation proceeds, it soon becomes saturated, so preventing further drying, unless it is continually renewed at the surfaces of the material that is to be dried.

Gelatine should never be completely desiccated; it is considered to be dry when it contains no more than about 10 to 15 per cent of moisture. Further drying renders it very brittle, a fault which would be specially evident with film negatives, and might also cause injurious effects in the case of glass negatives.

Drying in an atmosphere of less than 60 per cent relative humidity tends to dry the surface layer before the underlying portions; the evaporation of the imprisoned moisture is thus retarded. Injury may occur to negatives which are stored, or to films which are rolled, in this condition when the imprisoned water becomes re-distributed through the whole thickness of the coating.

The drying of films in motion-picture laboratories is carried out as a rule in a current of air at 70 per cent or 80 per cent relative humidity, at temperatures between 78°F and 87°F.

The evaporation of water is accompanied by

the absorption of heat, which, in the case of spontaneous evaporation, results in a lowering of temperature. Since, at the same relative humidity, the rate of evaporation of water decreases as the temperature of the water to be evaporated is lowered, it is seen that drying tends to become progressively slower. This retardation is all the more marked when evaporation takes place simultaneously from both sides of a negative; a drop of water adhering to the back of a negative often results in retarding the drying of the portion of the gelatine layer immediately opposite to it.

516. Apparatus for Drying. Glass negatives are generally dried in the vertical position in the grooves of a draining rack. Some drying racks are made with slightly inclined grooves; with these, the plates should be inserted with the gelatine facing downwards in order to prevent dust from being deposited on it. These accessories are not always made in the most rational form, folding racks being as a rule the worst offenders. In the first place they are often unsteady, being so designed as to cause the diagonal of the plate to be very far from vertical, which is the most stable position. Secondly, the grooves are almost always too close together, allowing an insufficient circulation of air between the plates—so much so that it is no uncommon thing to find water which has been evaporated from one coating condensed as dew on the back of the next plate. This is generally avoided by using only one groove in every two or three. If care has been taken to wipe the glass sides of negatives before placing them in the racks, two negatives may be placed back to back in adjoining grooves, each pair of negatives being separated from the next by at least one empty groove. Another plan is to arrange the negatives all facing the same way, in order to avoid mistakes; a constant interval is then left between each.

If, for any reason, a plate has to be dried without a rack, it may be rested against the wall with its lower edge on several thicknesses of clean white blotting paper.

Cut films, if they have been developed, fixed, and washed in developing hangers, are generally kept in these hangers until drying has been carried out, the hangers being suspended from special racks or placed in ordinary plate racks. In the absence of hangers, films may be suspended from a stretched string in the darkroom or some other room as free from dust as possible, or inside a drying cabinet, or they may be pinned

to the edges of shelves. Whatever method be adopted, films must be far enough from each other and from neighbouring objects to prevent their sticking together or to some other object, should they wave to and fro in a draught.

Lengths of film which are not much more than 3 ft or 4 ft long are generally hung by special clips to rods or stretched wires, the lower ends of the films being weighted by other clips of sufficient size to prevent the film curling.

Long lengths of film (motion picture films, aerial film negatives, etc.) are dried by winding them on special skeleton drums, which are kept uniformly turning on their axes. The film may also be fed into a drying cabinet and kept moving on a pulley system, until, at the end of the run through the cabinet it is dry. It will then be led out of the cabinet and spooled. In this way a continuous drying process is in operation and any length of film can be dealt with.

517. The Operation of Drying. Drying should be carried out in premises which are well ventilated, dry, and at a moderate temperature. Freedom from dust is another requirement, and for this reason it should be in a room where there is no need for constant passing to and fro—a certain means of raising dust. In commercial installations drying is carried out in special rooms into which dry, warm, filtered air, is forced.

It is essential that during drying there should be no sudden change of temperature, of relative humidity, or of speed of air currents. Every negative which is subjected to great changes in conditions of drying shows a distinct mark between the portions dried under different conditions. Those parts which have been dried most slowly may be more or less dense than the other areas. In particular, negatives must not be allowed to stand in the sun during drying.

Once the negatives have been placed in the racks or hung up, they must not be disturbed until they are dry, no matter how great the impatience to examine them may be.

Before drying, negatives should be wiped on the gelatine side (on both sides in the case of films) either with a rubber or synthetic sponge which has been well squeezed out in water or with a grease-free chamois leather which has been soaked and wrung out. For lengths of film, use may be made of a pair of squeegees, hinged at one end and elongated to form handles at the other.

On continuous-working machines for dealing

with films (motion-picture films, aerial film negatives, etc.), wiping is often done by jets of compressed air, which play obliquely on the two sides of the film. This air should be filtered in order to trap any drops of oil brought in from the compressor. For wiping a very small number of negatives, they may be placed between two sheets of fluffless blotting paper or between the leaves of a book of filter paper, the hand being then passed over the paper with moderate pressure. In this way the duration of drying is considerably reduced, and also drops of water are prevented from causing marks due to the local retardation of drying.

Whenever possible, the glass sides of plate negatives should be wiped dry with a soft cloth; in addition to the fact that drying is thereby slightly accelerated, it is easier at this stage to get rid of small particles of gelatine or other foreign matter which may soil the back of the plate.

In a humid atmosphere, a high drying temperature leads to an increase of density and contrast. Evaporation in a moist atmosphere is slow and consequently cooling of the gelatine is negligible so that the gelatine can become softened by the high temperature. This allows the silver grains to be rearranged to a certain degree. In a dry atmosphere the evaporation of water is rapid, this cools the gelatine and keeps the emulsion fairly firm in even comparatively warm air. Variations of 25 per cent have been noted, after drying in various conditions, in densities that were equal before drying (J. Crabtree; D. R. White, 1922).

Drying should never be undertaken in a place where there is a risk of the temperature falling low enough to freeze the water with which the negatives are impregnated; "ice flowers," which would be formed under such conditions, would leave their distinct impression in the gelatine.

Certain insects, cockroaches, ants, etc., especially in warm climates, devour gelatine. In places infested by these creatures it is a good plan to protect negatives during drying by a mosquito net.

In warm, humid, and stormy weather, the gelatine of negatives is sometimes attacked during drying by colonies of microbes. During the course of very slow drying which such weather causes, these microbes may liquefy the gelatine in places, leaving the glass support bare. This trouble occurs especially with non-hardened negatives, when straw packing or other such

material containing mildew is disturbed near the negatives during drying. In such atmospheric conditions it is advisable to hasten drying by bathing the plates after washing in water to which alcohol has been added (§ 520), or at least to finish washing in an antiseptic bath such as 3 per cent solution of phenol.

518. Distortion of the Image during Drying. Very slight deformations, quite negligible in the common applications of photography, occur in the emulsion during drying, especially near the edges. They may need to be taken into account in high-precision measurements (cartography, astronomy, etc.).

These deformations are mainly due to local inequalities of drying. They occur chiefly on negatives developed with a tanning developer (pyrogallol), as the denser portions of the image, which are tanned, contain less water than the surrounding gelatine. The presence of drops of water adhering to the gelatine surface, or even to the glass, causes similar deformations due to local retardation of drying. Every negative has a margin of about half an inch in which these deformations are fairly considerable. Distortion, which is due to inequality of drying, may be considered as temporary if the gelatine has not been hardened with alum, and with this exception it is possible to remedy the defect by allowing the negative to swell in water and to dry again with all necessary precautions, particularly by hastening drying by treatment with alcohol (§ 520).

519. Acceleration of Drying by Heat. The drying of glass negatives or paper prints may be greatly hastened by a current of warm air, or by placing the material to be dried near a source of heat, provided that the gelatine has been hardened to raise its melting-point to withstand the rise in temperature. The heating of the emulsion on a glass plate on which a current of warm air is directed can be limited by blowing a current of cold air on to the back (glass) surface at the same time. If heating, in this way, is excessive when applied to films, it often causes a permanent deformation of the film base (notably curling at the edges), which may be an obstacle to perfect sharpness of prints.

Negatives fixed in solutions containing alum, and especially in a fixing solution containing a large quantity of chrome-alum (§ 492), will generally stand a temperature of 120°F to 140°F. They may be dried in full sunlight, provided that no shadow falls on them, since

shadows would cause local inequalities of drying. Drying in the sun is indeed often the only possible method in very warm and humid climates.

In the case of negatives which have only a passing interest and from which prints are urgently required, the gelatine may be rendered proof against melting, even at the temperature of boiling water, by bathing the negative for about 10 minutes in a solution of formalin or formaldehyde. (The liquid sold under the name of formalin is an aqueous solution of about 40 per cent of formic aldehyde or formaldehyde, a gas. It will sometimes be found to change on standing; white clots of trioxymethylene being formed. When this happens, it loses its effectiveness wholly or partly.) A suitable dilution for this purpose is 5 parts in 100 parts of water, which is ample to give the desired hardening (J. McIntosh, 1900), and the low concentration has the advantage that a small amount of formaldehyde is liberated from the negatives during drying. When frequent recourse to this method of drying is necessary, it is best to obtain a sheet-iron drying box, through which air can be circulated and led to the outside, and in which the temperature can be raised to about 212°F. Drying by heat after treatment with formalin may be accelerated still more if alcohol is used in place of part of the water for diluting the formalin.

520. Rapid Drying with a Volatile Liquid. Many liquids evaporate much more rapidly than water, owing to their vapours not being commonly present in the air, and to the fact that their boiling points are lower than that of water, and also because their heat of vaporization is much lower than that of water (half for methyl and ethyl alcohols, quarter for acetone). Any of these liquids that are miscible in all proportions with water may be employed to hasten the drying of the gelatine of photographic negatives and prints; in the case of films there is, of course, the additional requirement that they must not dissolve the film base. After some minutes' soaking in the selected liquid the latter will have almost completely displaced the water and drying will then be very rapid.

Considerations only of cost suggest the use of denatured alcohol (methylated spirit), which has the added advantage that it causes the gelatine to contract. It may almost be said that alcohol does not penetrate the gelatine but merely extracts the water, the attraction of gelatine for water being very small or non-existent (H. R. Proctor, 1909). The alcohol, by

gradually taking up water, becomes useless for this purpose after it has dealt with a number of negatives, and requires regeneration. Too rapid dilution of the alcohol should be prevented by draining or wiping the negatives before placing them in it, and after the alcohol treatment is finished, the alcohol clinging to the negatives is allowed to drain into the bath before completely removing the negative. These precautions almost double the amount of material which can be dealt with by a given amount of alcohol (L. P. Clerc, 1917). Negatives of which some parts have already dried spontaneously should not be treated by this method on account of the risk of marks. Denatured alcohol diluted with water may be regenerated by shaking it with salts which take up water with great avidity and are not soluble in alcohol or water-alcohol mixtures, e.g. plaster of Paris or the carbonate of soda or potash.

The extra speed of drying is obviously greater when concentrated alcohol is used, but the use of methylated spirit at its maximum concentration presents various difficulties. In addition to the precipitation of lime salts from hard water in the form of a white opaque fog (§ 512), it sometimes produces a dulling effect on the surface of the gelatine, which has been attributed to the dehydration of the gelatine mycelles (Lüppo-Cramer, 1915). Concentrated alcohol can be utilized by employing two successive baths, of which the first contains a hygroscopic substance, for instance, crystallized calcium chloride (2 g per litre) (Schering and Kahlbaum, 1928), or a non-hygroscopic substance conferring pliancy, as for instance, urea (1 g per litre), or salicylic acid (10 g per litre) (Zeiss-Ikon, 1930). Also, the use of concentrated alcohol, by softening the base of film negatives and dissolving an appreciable proportion of the plasticizers, may cause frilling of the gelatine or permanent deformation of the film.

The following table shows the time required for drying negatives (7 × 5 in.) after 10 minutes' treatment in denatured alcohol to which water has been added in different proportions. These times are of course only relative, for they must depend also on the thickness of the gelatine and on the atmospheric conditions—

Water (added) Time of drying	Pure denatured alcohol						Pure water	
	0	20	40	60	80	100	100	100
%	40 min	80 min	115 min	175 min	210 min	270 min		

It will be seen that whilst the effectiveness of alcohol decreases very quickly with dilution, alcohol diluted with water to a moderate extent

(up to 20 per cent) is still considerably more rapid than spontaneous drying, and yet avoids the various troubles which may result from the use of too highly concentrated alcohol. Methylated spirit becomes turbid on adding water because of the precipitation of lime salts from the water and of resinous or tarry substances present in the denaturing agent. Very clear dilutions of alcohol may be obtained by adding a small amount of ammonia (1 ml per litre), shaking with several changes of animal charcoal (about 20 g per litre) and filtering or decanting the clear liquid (A. Ninck, 1926).

Negatives which have been passed through alcohol may, during drying, be subjected without harm to a higher temperature than would be safe for negatives heavily charged with water.

After treatment by the alcohol method of drying, there is a temptation to consider negatives to be dry which are really only dry on the surface and in which the deeper parts of the gelatine are still wet. If such negatives are piled together in this condition it may be impossible to separate them afterwards.

521. Instantaneous Drying by Dehydration of the Gelatine. Certain salts which are very soluble in water may be employed in very concentrated aqueous solutions in order to bring about the rapid dehydration of gelatine impregnated with water without causing any ill effects on the gelatine itself (Lumière and Seyewetz, 1912). Among the salts which may be used (aluminium sulphate, sodium sulphate, sodium thiosulphate, etc.), potassium carbonate in saturated solution gives the best results

without harming the negatives, even in the case of prolonged contact.

This method of drying should be considered as suitable for the *temporary drying* of negatives, permitting of their immediate use for periods up to several weeks. They must be given a further washing in order to get rid of traces of potassium carbonate from the gelatine. The washing of a plate or film impregnated with a very concentrated solution of salts should, preferably, be begun in a dish, using repeatedly just sufficient water to cover it, in order to avoid too sudden a change in concentration which might cause reticulation of the gelatine.

Potassium carbonate after a time, may give rise to stains, or, in certain cases, to the separation of the film from its support. Since the washing of the negatives must be repeated later on, the first washing and even fixing may be shortened, these processes being completed later.

The negative containing water is immersed for 4 or 5 minutes in a saturated solution of potassium carbonate (about 53 per cent at 60°F) or 110 parts of the salt to 100 parts of water; (this solution registers 52.5° on the Baumé hydrometer). The negative is rapidly wiped between blotting paper to remove the bulk of the adhering solution, and drying is completed by wiping the film with a soft cloth. The surface, which is very hard, is of glossy appearance. The negative may be used at once for printing.

The solution of potassium carbonate may be regenerated from time to time by dissolving more of the salt in it.

CHAPTER XXXII

THE CHIEF FAILURES IN NEGATIVE-MAKING

522. Preliminary Note. The enumeration of the faults which may occur during the various phases of the process of negative-making may be sufficient to discourage the novice in photography; it has, however, no other purpose than to allow the cause of a failure to be discovered. It must be admitted that any list of possible defects is never complete, unexpected failures sometimes occurring which cannot be traced to their causes.

When a beginner (and sometimes even an experienced photographer) meets with a failure he immediately blames the camera, the plates, the chemicals and their respective purveyors; almost always he forgets to ask himself what blunder he has committed.

Nobody is infallible, and, in spite of strict control, a manufacturer (of whom one cannot ask that he should test all his plates and films before issuing them for sale) will send out—but very seldom—a plate or film showing some slight defect. Long experience shows, however, that the great majority of failures are due to faulty working of which the photographer is often unconscious, and which he will not hesitate in good faith to deny.

If, after careful investigation, a fault appears to be due to manufacture, and is repeated on several plates from the same box or from the same emulsion, replacement may be demanded from the manufacturer. This will always be courteously furnished if it be courteously asked. In addition to the faulty negatives, some other plates (exposed or otherwise) which have not been developed should be returned, packed in their original wrappings.

523. Faults Appearing During Development.¹ *The Image Does Not Develop.* Anti-halation plate exposed through the back; plate not exposed; absence of one of the essential ingredients from the developing solution. Put the plate aside for the time being in pure water, and then try to develop it later in another bath. A slow appearance of the image may be due simply

to putting the plate in the developer upside down.

The Emulsion Darkens Before any Image Appears. The sensitive surface has been exposed to light outside the camera or has been affected by X-rays or other penetrating radiation.

The Image Appears Almost Lost by Uniform Fog. If those parts of the sensitive emulsion which were protected by the rebates, etc., of the dark slide are not fogged, the trouble is probably due to excessive exposure; to sunlight on the lens during exposure (absence of lens hood); or to the use of a lens of which some parts are dirty or covered with mist.

If the fog also covers the protected parts of the surface, several causes may be suspected: long storage of the plate or film under unfavourable conditions; wrongly-mixed developer (excess of alkali, insufficient bromide), or developer contaminated with thiosulphate or metallic salts from the materials of which dishes and accessories are made, or with sulphide formed by bacterial action in old developing solutions which have been kept for a long time. In either of these cases of fogging the cause may be (§ 200) the action of certain materials used in the construction of the dark slide (resinous wood, varnish, drying oils, or of paper used for re-packing the plates or films between exposure and development). Prolong development as for a normal negative adding a fairly large amount of bromide or antifoggant. In spite of being very dense, the negative will yield passable prints.

Fog Appears After the Image is Distinctly Visible. Development is being done too close to a darkroom lamp which is fitted with an unsuitable safelight screen; or a very little diffused light is penetrating to the inside of the darkroom. In these cases the sensitive surface in the shadow cast by the sides of the dish remains clear of fog. In the case of a developer containing hydroquinone, the fog may be due to aerial oxidation of the developer as a result of too prolonged withdrawals of the negative for examination (§ 387). These failures may be avoided by desensitizing.

Intense Ray-like Fog. Fog starting as a rule from one corner or edge and throwing rays in

¹ Some of these defects, especially if they are not very marked, will not be found until later, sometimes not until after drying. For the characteristics of negatives which have been under-exposed or over-exposed, see §§ 334 to 336.

different directions indicates leakage of light in the dark slide or its junction with the camera. Similar directed fog on roll-films is due to leakage of light between turns too loosely wound when the film is removed from the camera. Such light at grazing incidence can be recognized by the long shadows cast by any small protuberance, which are recorded in the fog.

Marginal Fog. Fog forming a black or dark grey border and falling off towards the centre sometimes occurs on plates or films which are very old or which have been kept under bad conditions. This may occur on two edges only.

Parts of the Emulsion do not Develop, or Develop only Slowly. The surface of the emulsion has not been fully covered by the developer, probably because too little solution has been used and this has not been well stirred; possibly, also, to the dish or tank not being level. In tank development access of developer may be obstructed by improper contact of the emulsion with another piece of sensitized material, or with the rack or other device for holding the material.

Black Lines Covering the Whole or Part of the Plate. During the preparation for taking a photograph, or when carrying the camera, an image of the sun is formed on the sensitive surface by a tiny hole in the camera itself. This acts like a pinhole, and moves in all directions according to the movements of the camera. Parts of these lines may be reversed by solarization. Similar tracks of the images of electric-light bulbs may show striations due to the supply current alternations.

Black Spots Irregularly Distributed over the Image. Black spots of various shapes and sizes may be due to specks of some substance which causes fog or accelerates development. These may fall on the surface as dust or as particles from the developer itself. Dust may arise from the friction of the slide in an aluminium film or plate holder. They may also be due to undissolved particles of the ingredients in an unfiltered developing solution; crystallization may also occur in a concentrated developer when the temperature falls too low. These spots sometimes have tails, which are usually vertical, when tank development has been employed. When dust has fallen on the surfaces before exposure to light, the black spots may have a transparent centre.

Black or white spots may be due, in exceptional cases, to a local increase or decrease of sensitivity during manufacture, owing to the acidity or oxydation-reduction equilibrium of the

emulsion being modified by microscopic foreign inclusions or bacterial growths.

Pseudo-reticulation. Dark lines somewhat like the meshes of a net have been caused in many cases by development in a bath which is not rocked or in a dish which contains only a small quantity of developer.

Edge and Streamer Markings. When development is done in a very shallow layer of solution in an unrocked dish, there are sometimes produced dark margins on the dense regions of the image and light margins on the adjacent lighter regions. This is due to diffusion exchanges between the active developing agent and the products of reaction. For the same reason, when vertical tank development is employed, light streamer markings, extending below the denser parts of the image, are produced.

Irregular Stream-lines, Darker or Lighter than the Rest of the Image. The developer was not perfectly mixed when plates or films were placed in it. It may not have been sufficiently mixed when a concentrated developer has been diluted, or when the solution has been prepared from various stock solutions. Stream-lines spreading from the clips of hangers or other holding device may be due to an unsuitable metal or solder used in its construction, or to its previous contamination with hypo. In the latter case a lighter band with a glossy surface may have darker edges. In very low concentration hypo accelerates development, giving the dark edges, while in slightly higher concentration it retards development and may even dissolve the surface grains giving the glossy finish when dry.

Mottling. This defect is usually the result of curtailed development of a much over-exposed negative, the developer being dilute or exhausted and insufficiently rocked.

White Spots. Several cases must be considered. Tiny areas bare of emulsion would result in completely transparent areas *before fixation*, and would be recognized after drying by the depressions in the film. This defect is extremely rare. White spots, which on great enlargement are found to have sharply-defined irregular edges, usually angular, are the shadows of dust deposited on the emulsion before exposure to light. Little white spots with no foreign speck in the centre, circular or oval in shape, are generally due to air bubbles preventing the developer from coming in contact with the emulsion; they frequently occur when the developer has been diluted with water taken from a high-pressure supply, or with water at a lower

temperature than that of the darkroom and which, on being warmed, liberates some dissolved air. Air-bells adhering to the emulsion when the developer has not been poured uniformly on to the plate are usually of a sharply-defined rounded shape, but irregular. Lines of air bubbles are sometimes formed when development hangers or holders of films are used and are introduced suddenly into the developer.

White or Clear Spots, Round or Irregular, with Graded Edges. These spots are generally due to splashes of water on the emulsion, or to condensation of moisture when camera or slides have been in a very cold atmosphere, and are brought into a warm place. Similar circumstances sometimes produce mottled markings, or marks with a light marginal fringe. In tropical climates, spots arising from splashes sometimes have either a dark centre or a dark ring. Very rarely such spots are due to dust contamination of the gelatine layer during manufacture. In such cases a central speck may be visible under a magnifier.

Finger-markings. Finger-markings appear white after contact of dry fingers with the surface of the emulsion (and even with the backs of the plates if the latter are piled together after contact). The slightest quantity of grease deposited on the emulsion prevents the penetration of the developer. Finger-markings will appear black if the surface of the emulsion has been touched with fingers soiled with developer, fixer, etc.

Black or White Lines. Lines, generally very fine and straight, are due to friction on the emulsion. The slide of the film or plate holder may be bent; there may be abnormal resistance to the pulling over of films in a bent film pack; the guide rollers may be working badly in a roll-film camera, or it may be winding too tightly. Lines from these various causes are usually light on a dark ground and dark on a clear ground.

These lines are not to be confused with the broad and very opaque bands with diffused edges which are due to the passage of light between the sections of the curtain shutter of a dark slide, nor with the broad black lines with shaded edges which start perpendicularly to one edge of the plate and end in a black disc (or vice versa). These latter are caused by the movement and subsequent stopping in front of the plate of a hole in the blind of a focal-plane shutter. (Such holes are often caused by burning of the rubber of the blind occasioned by the focused image of the sun.)

Dark Tree-like Markings. Static electric discharges on an emulsion leave black brush- or tree-like markings. This trouble is hardly ever met with except on films, and then only in very dry weather (especially in frosty weather). It may be due to friction or merely to the unrolling of the spool.

The Image Appears as a Positive. An image which has been considerably over-exposed may appear as a positive, altogether or partially; in such cases it is usually fogged. An image which at first appeared as a negative may during development be converted into a positive by the action of light (white light or unsafe darkroom lighting); it seems in this case that the first negative image protects the underlying emulsion against fog; at the same time the sensitivity of the emulsion is decreased by the soluble bromide already set free by development. Delayed reversal may also result from very long development in an extremely dilute developer; the chemical fog of the unexposed regions becomes denser than the image itself.

Double Images: Ghosts. The superposition of two entirely different images is obviously caused by two exposures on the same plate or on the same part of a film. Very curious effects are sometimes caused, however, by the superposition of two exposures without moving the camera; the shutter may have been opened twice or it may have rebounded, or it may be that the sensitive surface has remained uncovered for some time, and a second image has been projected by means of a hole in the front of the camera; one of these images is always so faint that only persons dressed in light colours standing near during or after the exposure appear in it; such figures then appear as transparent ghosts. These effects are often attributed to supernatural causes!

Broad Transparent Shaded Mark, Starting from One Edge. A very large out-of-focus image of a finger, held in front of the lens during exposure, so that it obscures part of the field.

Broad Light Bands Parallel to One Side of the Plate. When a focal-plane shutter is used, the rapid passage of an opaque body in front of the lens cuts out the image (or reduces its density if only a portion of the lens aperture is masked) on the parts of the plate which happen at that instant to be uncovered by the slit of the shutter.

524. Defects Appearing After Fixing. *Milky Markings with Diffused Edges, visible on the Back of the Negative or by Transmitted Light.* Fixation has been stopped too soon, and has

left patches of silver bromide between the image and the support.

Transparent Marks of Irregular Shape and with Diffused Edges. Local solution of metallic silver in an old fixing bath, which contains particles of rust, or in any fixing solution containing particles of potassium ferricyanide or other reagents capable of attacking silver. A clear mark may be produced by the prolonged action of a crystal of undissolved thiosulphate on a part of the emulsion.

A uniform opalescence of the gelatine is sometimes observed on removing a negative from a strong fixing bath. It is due to dehydration and disappears on washing.

Blisters. Blisters may be caused, particularly on films and papers, by bubbles of gas, which, instead of being liberated at the surface, are formed within the gelatine itself or between the latter and the support (immediate use of water delivered at too great a pressure; transference without intermediate rinsing from a developing solution containing carbonate to a very acid, non-hardening, tepid fixing bath).

Yellow or Brown Stain, Local or General. General stain may be due to the staining action of products of development on the gelatine. This occurs if the developer is old and highly-coloured, or if it contains insufficient sulphite. Stains in patches may be caused, especially with films and papers, on portions of the surface which during the first few moments of fixation have not been immersed in the solution. Solutions of alum, sometimes proposed for the removal of these stains, are quite useless, but the stains may be destroyed as follows. After washing the negative, immerse it for about 5 minutes in a solution of 5 per cent chrome-alum, in order to complete the hardening of the gelatine and to avoid any softening during the further treatment, and then rinse it rapidly. The image is then bleached in a mixture of equal volumes of the following solutions (A) and (B), which should be mixed fresh when required.

(A) Permanganate of potash	5 g
Water to make	1 litre
(B) Hydrochloric acid	50 ml
Water to make	1 litre

After the image has been bleached it has a general brown coloration due to manganese oxide deposited in the gelatine. The negative is rinsed and is placed in a 5 or 10 per cent solution of sodium bisulphite until the brown

colour has disappeared. The image is then blackened by treating it in an ordinary developer in full white light until no more white silver chloride remains visible through the back. Finally, wash the negative in two or three changes of water without fixing. The above treatment may be applied to a negative even if it has been dried.

An iridescent yellowish-brown silver stain is sometimes produced by physical development on to nuclei of silver sulphide formed in the emulsion surface by traces of sulphide in the developer. Such soluble sulphides are usually due to bacterial growth in the developer. The stain can often be removed from the dry negative by firm wiping under spirit (not anhydrous).

525. Dichroic Fog. The fog generally known as dichroic, although it does not always show two complementary colours, most commonly appears greenish-yellow by reflected light, and pink or purplish by transmitted light. It consists of ultra-microscopic particles of silver (colloidal silver) formed when silver bromide is subjected simultaneously to the action of one of its solvents, and to that of a developer capable of reducing silver salts *in situ* as soon as these salts are dissolved.

The conditions necessary for the formation of dichroic fog may thus prevail during development and also during fixation. The milky appearance (by reflected light) of this fog often leads, in the dim light of the darkroom, to its being mistaken for a residue of undissolved silver bromide.

Dichroic fog hardly ever occurs during development, except in the under-exposed portions of a negative where there is no silver reduced in its ordinary black condition,¹ and when development is prolonged in the empty hope of bringing up detail which the light has not registered or when slow-acting developers like hydroquinone or glycin are used. The solvent causing its formation may be hypo accidentally introduced into the developer, or it may be ammonia added as such or as an ammonium salt, or it may be sodium sulphite used in excessive amount. Lüppo-Cramer (1905), however, obtained dichroic fog in a developer containing only sodium carbonate and an amino developing agent, substances of this latter class behaving as feeble solvents of silver bromide.

¹ Where the silver is already reduced it plays the part of a nucleus on which is deposited silver, which, in the clear parts, forms in the colloidal condition.

If formed during fixation, dichroic fog may extend over the whole or part of the negative without any relation between its distribution and that of the image; its formation is due to developer carried over into the fixing bath by the gelatine of the negatives. A neutral fixing bath favours its formation because in such a solution the developer retains its activity until it has become diffused into the bulk of the solution; a very old fixing bath also favours its production, because of the accumulation of developer in it. Dichroic fog can, however, be formed in a fresh acid fixing solution if two film negatives or paper prints adhere to one another during fixation, because in this way the free access of the fixer is prevented; the developer is thus in excess of the fixer, and so the ideal condition for the formation of colloidal silver is provided. In all cases the presence of ammonia or of ammonium salts, and the exposure of the plate to light before fixation is complete are circumstances favourable to the appearance of dichroic fog.

The occurrence of dichroic fog during fixation is almost certainly avoided by rinsing negatives between development and fixation, especially if the rinsing is done in slightly acidulated water.

The only practical reagent known to dissolve this colloidal silver without attacking the image—that recommended by J. Hauff in 1894—was, for several years—

Thio-urea (thiocarbamide)	1 g
Citric acid	1 g
Water to make	100 ml

As the outcome of an experimental study of this trouble, Lumière and Seyewetz (1903) recommended bathing the negative for 5 minutes in a 0.1 per cent neutral solution of potassium permanganate; after rinsing, the negative is placed in a solution of 5 per cent to 10 per cent sodium bisulphite in which the silver oxide formed by action of the permanganate and also the brown colour of manganese dioxide formed in the gelatine disappear. The process is finished by washing in two or three changes of water. A dilute solution of potassium cyanide (0.5–1.0 per cent) slowly dissolves the colloidal silver in the presence of air.

526. Defects Occurring During Washing. Reticulation. The reticulation of gelatine, giving it the appearance of grained leather or crocodile skin, is due to the excessive swelling which may arise from various causes. One is transfer from a very concentrated or warm fixing bath

into cold water, especially if the fixing bath contains no alum. Another is a considerable difference in temperature, one way or the other, between the developer and the fixing bath. In general, reticulation is liable to be caused by any circumstance tending to cause very rapid swelling or shrinkage of the gelatine, such as transfer from a very alkaline bath to one which is strongly acid, or inversely. When the reticulation is not very marked, it is sometimes possible to remedy it by placing the negative in alcohol (with films, at least 20 per cent of water must be added to the alcohol), and then hardening it with alum, if necessary, before proceeding to any other operation.

Frilling of the Gelatine at the Edges. This defect, which starts as a kind of curling along the edges of the support, is due to the same causes as reticulation; the same methods may be tried in order to prevent it.

Transparent or Clear Spots of Irregular Shape. Local attack of the gelatine by liquefying bacteria during prolonged washing, particularly in warm weather.

527. Defects Appearing During or After Drying. Partial Melting of the Gelatine leading to Irregular Deformation of the Image. The negatives have been subjected to a temperature above the melting point of gelatine whilst in a wet and insufficiently hardened condition. They may have been placed too near a fire or in the direct rays of the sun.

Patches of Uneven Density. Local variations in the rate of drying due to changes of temperature, humidity, or speed of air currents. These patches may sometimes be got rid of by converting the image into silver chloride and re-developing as described in § 424 for removing developer stains.

Light Spots or Marks with Dark Edges. These marks are caused by drops of water left on the face of the gelatine during drying, or which have been splashed on to its surface after it has already dried. In course of drying these splashes dry first at the edges of the moist region and cause the particles of silver to be dragged from the centre towards the edge. Re-wetting of the negative, followed by normal drying, does not always provide a remedy for this.

Clear Spots of Bare Glass or Film. Local liquefaction of the gelatine by colonies of bacteria during very slow drying in a warm, moist atmosphere. Clear, irregular spots may be due to the attack of various insects on the gelatine.

Metallic Stains on the Edges of the Negative. Opaque fog of a lustrous metallic appearance, generally seen only on the edges of the negative, may be due to the use of an exhausted developer with old emulsions, or to a superficial sulphiding of the silver by hydrogen sulphide (often present in the atmosphere of industrial towns). It may usually be removed by dry rubbing with chamois leather; in obstinate cases, moisten the leather with methylated spirit in order to increase the friction, but in any case rub very lightly.

Traces of Foreign Matter Embedded in the Gelatine. Dust, particles of fibre, etc., deposited by the washing water and not removed by a final rinse in filtered water, or deposited during drying.

Distorted Films. A film which has been dried too rapidly (in too dry and warm air), under excessive tension, is often waved at the edges. The remedy consists in washing until the gelatine is uniformly swollen, and then drying under normal conditions.

White, Granular Deposit. This deposit, which is quite distinctly rough to the touch, is caused by the deposition of lime salts from a very hard water when no final rinsing in soft water has been employed. It may be removed by washing in slightly acidified water (1 per cent hydrochloric or acetic acid is suitable, but non-volatile acids must not be used) and again drying. Negatives should be gently wiped with the fingertips under the tap before they are put to dry.

White, Powdery Deposit. This is usually caused by aluminium sulphite deposited in or on the gelatine from an acid-alum fixing bath in which too much of the acid has been neutralized. It may be removed by wiping under the surface of a solution of sodium carbonate (about 10 per cent) followed by washing in clean water.

Yellowish-white Opalescence. This veil is generally due to the deposition of sulphur in the gelatine caused by the acidification of a fixing bath containing insufficient sulphite, or by the use of an acid fixing bath at too high a temperature, or by treating the negative with alum before or after fixation without intermediate rinsing. The only possibility of dissolving this sulphur without affecting the image is, after thoroughly hardening the gelatine, to try to convert it into sodium thiosulphate in a warm solution of sulphite (10 per cent solution of anhydrous sulphite of soda, warmed to about

110°F), in which it is allowed to remain for some minutes. The process is finished by washing in several changes of water. The treatment is not successful with old negatives.

Silvery-white Opalescence which is Yellow by Transmitted Light. This variety of white deposit, covering all or part of the image, and particularly parts which have been dried too rapidly (edges), is caused by too rapid dehydration of the gelatine by concentrated alcohol (neat methylated spirit), especially if the negative has been washed in very hard water. It may be removed by washing in slightly acidified water (see "White Granular Deposit"), which method may also be employed as a preventive.

528. Defects Occurring in a Negative After Drying. **Ink Marks or Stains of Aniline Dyes.** Black ink stains (indian ink excepted) or coloured stains arising from dyes or any coloured substance (including dust from a copying pencil) disappear entirely under the treatment described in § 424 for developer stain.

Brown Stains. Brown stains may appear on a negative after a lapse of time ranging from some weeks to several years (more rapidly in a moist atmosphere). This is due to the slow conversion into silver sulphide of silver thiosulphate left in the negative after incomplete fixation or washing (in the latter case there is often a general weakening of the image in the region of the stain). There is no certain method of removing this kind of stain; it is often better to make a new negative from a print taken before the defect arose, or to make, first, a positive transparency (§ 899) on a panchromatic plate through a deep orange filter and then a fresh negative from that. The effect of the stain is thus greatly reduced.

Scratches. The effect of various fine markings, produced by friction, may be reduced by varnishing the negative (§ 575).

Cracked Negative. A cracked negative, of which the gelatine film is intact may be saved by stripping the film to another support (§ 580), provided that the broken glass is supported during manipulation. This may be carried out very simply as follows. Take an old, waste negative, and dip it in water for a very short time, so that the gelatine does not swell appreciably, then slide the back of the cracked negative gently on to the moist gelatine so prepared. The very thin film of water interposed is absorbed by the gelatine and perfect adhesion of the two negatives is then assured on account of atmospheric pressure.

CHAPTER XXXIII

REVERSAL PROCESSES: METHODS FOR OBTAINING DIRECT POSITIVES

529. **General Considerations.** We will first mention a method which cannot, properly, be considered as a reversal process, but which is sometimes employed for obtaining positive images directly. By developing so as to obtain silver, which is whitish by reflected light, and employing plates in which the emulsion is coated on a black or very dark support, the image appears as a positive. This method is chiefly used for making "ferrotypes," also known as tintypes. A variation of this method has been used by the American Army Air Force (1925) for the rapid examination of negatives taken during urgent reconnaissances. The support in this case is of blue-violet celluloid, appearing almost black by reflected light, but through which positive prints may be made. The image is negative for transmitted light although positive by reflection. An ordinary negative image on a transparent support may also be made to appear as a positive if the black reduced silver is converted into a white salt of silver, and the plate is then given a black backing. This method is sometimes employed for printing from a very flat negative. The negative is bleached with mercuric chloride, rinsed, dried, and mounted against a black ground. A copy can then be taken.

The methods of reversal, properly called, may be classified as follows—

(a) By considerable over-exposure; the image is *solarized* (§ 210) and develops directly as a positive.

(b) A sensitive material is uniformly 'fogged' to a high density and is then exposed to the image under such conditions that on normal development the fog density is reduced in proportion to the image exposure. As a rule radiations of different qualities are used for the fogging and the image exposures.

(c) After normal development of a negative which has been normally exposed and has not been desensitized, only a part of the thickness of the emulsion will have been employed in obtaining the negative image; the remainder is still sensitive to light (although its sensitivity may have been reduced). It is therefore possible, by exposing the negative to light, to produce in this residue a latent positive image which will remain, although weakened, after dis-

solving out the silver of the negative image and may be developed so as to give the final positive image (C. Dronillard, 1901).

It is possible to obtain a positive image by a similar procedure without dissolving the negative silver image first (F. Leiber, 1932). The positive image is developed in a developer which produces a stain image as well as a silver one (§ 413). All the remaining silver bromide and silver are then bleached away and the stain image is intensified.

(d) It has been noticed (J. G. Capstaff, 1921) that, after the negative image is dissolved, the speed of the remaining silver bromide varies considerably from one point to another, being the less at each point the more the quantity of silver dissolved there. As a matter of fact, the various grains of silver each have different speeds, and in each spot it is the fastest grains which, during the first exposure, are brought first into developable condition; thus there remains in the image of the shadows the majority of the most rapid grains, while the slowest grains alone remain in the image of the high-lights. A uniform, and properly controlled, second exposure can therefore produce an effect practically identical to that of exposures, variable from one point to another, corresponding to printing a positive under a negative; what happens is almost as if the second exposure to light were made under the first (negative) image, although the latter has been removed. Development and fixation then follow, just as with an image obtained under ordinary conditions.

(e) In a negative which has been developed but not fixed there exist two images. These are complementary to one another, but generally of very unequal quality; one is the negative image, consisting of reduced silver, and the other is a positive image, consisting of the residual silver bromide. Whilst dissolving the silver bromide (fixation) only leaves the negative image, the removal of the silver by a solvent having no action on the bromide leaves the positive image. All that is then needed is development of the silver bromide to the state of metallic silver or of some compound of suitable colour (C. Russell, 1862). This method was applied in practice for the first time by Lumière

for the production of colour photographs on Autochrome plates.

530. In view of the very heavy exposures necessary in order to produce a solarized image, method (a) is quite impracticable for camera photography and is even difficult to apply for copying work, largely because the results are often not reproducible or are non-uniform.

There are numerous versions of method (b); one may utilize the effects described earlier (§ 209) under the name of *Herschel, Clayden* or *Villard* effect, or, better still, a procedure already mentioned in connexion with infra-red spectroscopy (§ 237). According to a technique described by Lüpbo-Cramer (1923), this method is applied for the production of auto-positive emulsions. Special emulsions for the production of auto-positives by an analogous process, have been worked out by H. Arens, J. Eggert, and E. Heisenberg (1931). With these, a laterally reversed duplicate of a negative or positive can be obtained by exposing the material in contact with the original for a time from 10 to 500 seconds at a distance of three feet from a 40-watt tungsten lamp.

In its original form, method (c) is difficult to apply, since all silver-solvents will attack the finely divided latent-image silver. The version suggested by Leiber has found numerous applications. Another version is applied commercially for the production of positives in multi-layer colour films. After the negative development, the film is exposed uniformly to light, and development is continued in a colour-forming developer. (§ 416). Finally, all the silver and silver halide is removed in a "reducing" solution to be described below under the name of Farmer's reducer (§ 566).

For many years method (d) has given perfect results in amateur sub-standard cinematography. It allows errors in exposure to be compensated for within wide limits, but requires a very accurately controlled second exposure. This is best done by preliminary tests on pictures taken under the same conditions as those to be treated. The method is only practicable in cinematography, since here it is always possible to sacrifice for testing a few frames from each scene. It is chiefly used for amateur films processed on continuous machines with a device for automatic adjustment of the exposing light according to the average amount of silver bromide remaining after the dissolution of the first image. This adjustment is effected by means of a thermo-electric couple sensitive to a

beam of infra-red light transmitted by an image without affecting its emulsion; a relay postpones this adjustment until the image that has been measured appears in the exposing window.

Reversal by the "residue" method is better suited for treating individual images. Various means of augmenting its flexibility will be described.

It is obvious that reversal cannot be applied to plates or films coated with several superposed emulsions; the best results are generally obtained with sensitive material specially prepared for this treatment.

Whatever the working method employed in procedures (c) to (e), it is essential that the first development be thorough, for the undeveloped latent negative image would be superimposed on the positive image, being able even to cause a re-reversal in the image of the high-lights.

531. **The Production of Autopositive Contact Prints by destroying a Latent Fog.** A fine-grain silver-bromide emulsion of the lantern-plate type is uniformly fogged so as to obtain on processing the maximum density required afterwards in the positive image. It is then bathed for two minutes in a solution containing 0.01 per cent of safranine and 1 per cent of potassium bromide. The material is dried without washing.

The emulsion layer so treated is then exposed in contact with the negative or positive one wants to duplicate. According to the density of the original, the exposure should be some 30 to 50 times as heavy as that needed to produce the fog. If the intensity is kept low and time of exposure long, the tone range of the process is considerably longer than for short exposure times and high intensities; in a certain instance, an exposure of 36 minutes allowed four times the range to be reproduced as an exposure of one minute with a correspondingly adjusted intensity (Lüpbo-Cramer, 1927). The only difficulty in preliminary tests is to establish the most favourable conditions of the two times of exposure which give the optimum results. A sensitometric step tablet is almost essential for this work.

Any developer is suitable for this process. One should avoid, however, developers which act very slowly, and those containing a silver-halide solvent. These latter are liable to develop the internal latent image of the first exposure, since it is only the superficial latent-image specks which are destroyed by the second exposure.

532. Reversal by Means of a Second Controlled Exposure. Since this method is not practicable except in automatic processing machines, there is little point in discussing technical details, but the principles of the method are of some fundamental interest.

V. B. Sease (1931) has, however, described a method which does not require automatic compensation or the preliminary testing of samples. A second exposure is given which is so adjusted as to be definitely too weak. This is followed by brief development and a further exposure is estimated from the character of the developed image. Further exposures are given as necessary, each followed by development, until a satisfactory positive is obtained. These operations are facilitated by the fact that the reversal bath destroys the dye sensitizers and reduces the sensitivity. According to F. Leiber (1932) the gamma of the resulting positive is reduced if the second exposure or exposures are applied from the back.

In the high-light portions of a negative, all the fastest grains of an emulsion have been used; in the half-tones or shadows, the fast grains remain unused to a smaller or greater extent. It is thus easily seen that the average sensitivity of the remaining emulsion varies considerably from point to point.

The local differences in sensitivity are accentuated by yet another factor (H. Baines, 1936). In the course of the first development, the iodide always present in fast emulsions is released and reacts with the neighbouring grains, which are thereby coated with a superficial layer of iodide and consequently reduced in sensitivity. This effect is more pronounced the larger the amount of silver produced during the first development.

The *Albert effect* (§ 209) also comes under the present method of reversal; it has been explained by G. W. W. Stevens (1939) in the following fashion. The superficial latent image is easily destroyed by the oxidizing treatment used to destroy the negative latent image. The internal latent image specks are not destroyed and act as condensation nuclei for any further latent-image silver produced during the second exposure. For grains which have received no first exposure, the latent image will be formed on the surface as usual. The second development thus acts only on the grains carrying superficial latent image specks; it cannot react with the internal latent image, unless the internal specks are laid bare by dissolving the outer layers of the silver halide grains.

The average sensitivity of the remaining emulsion is the greater the shorter the first exposure, i.e. the smaller the number of grains affected by the first development. By arranging the two exposures properly, practically identical positives can be obtained for first exposures varying as much as 16 to 1, if the tone range (ratio of the extreme brightnesses in the subject) does not exceed 30 : 1.

533. The Sensitometry of Reversal Emulsions. By contrast to the negative photographic images, reversed images are built up essentially from the finest grains in the emulsion, some medium-sized grains occurring in the middle tones, and a few large grains in the shadows. The graininess of the reversed image is thus considerably less than that in a negative obtained with the same emulsion or in a positive obtained by printing. Furthermore, if two samples of the same emulsion are developed to a negative and a positive respectively, the threshold sensitivity is often considerably greater for the positive than for the negative (H. Staude, 1938).

An ideal reversal emulsion should therefore contain a sufficient number of large grains to give it sensitivity, and of small grains to produce a brilliant picture of low graininess. An ordinary negative emulsion yields a reversal image of rather low contrast; a positive emulsion would be too insensitive.

For the method of reversal of the residue of an emulsion, whether with or without the application of a silver-bromide solvent, the two concepts of total black and density of solarization are of importance (L. Lobel and J. Lefevre, 1927). The total black is the density that would be obtained if all the silver-halide grains throughout the depth of the emulsion were reduced to silver. The solarization density is the maximum density that can be obtained in a given developer for a certain exposure, called the solarization exposure. Beyond the solarization exposure, the density stays constant for some while and then decreases; it is always less than the total black.

Let us consider the characteristic curve N of a negative, represented diagrammatically in Fig. 33.1. The total black of the emulsion is represented by the horizontal line T . When the silver developed as a negative has been removed, and the remaining silver bromide reduced to silver, the resulting positive is represented by the line P . The lowest density of P is d_0 ; this must be considered as being much too high to represent the high-lights of the scene. The lowest positive density would be higher

than d_0 , if the exposure were less than a critical value, which is determined by the maximum brightness of the scene and not by the minimum shadow brightness as in negative work (§ 336). If the exposure exceeds but slightly the critical value, several half-tones would merge with the high-lights. Thus it is clear that the method of reversal of the residue of an emulsion has no exposure latitude whatever.

If a suitable silver-halide solvent is used, which is as a rule added to the developer, the maximum black is reduced. In practice, it is reduced to a new value T_0 which should be as close as possible to the maximum solarization density. The resulting positive curve P' is obtained by moving the curve P downwards bodily, so that the minimum density d'_0 can be made as small as desired, by arranging a suitable concentration and time of treatment in the silver-halide solvent. By this method the effect of a reduced exposure can be compensated for by increasing the time of development, an effect which has no parallel in negative-positive work. The use of a silver-halide solvent in the developer thus introduces a certain degree of exposure latitude, although this is much less than can be obtained by using a controlled second exposure.

In order to ensure correct tone reproduction the gamma of the positive curve should be as near unity as possible. In other words, the gamma of the positive should be equal to that of the negative, but, of course, of opposite sign. On the one hand, one would like to push development to the maximum in order to ensure that the value of the solarization density s is high; on the other hand, the gamma of the final positive should not differ materially from unity. These conditions are not always realized in practice.

534. The curves in Fig. 33.2 represent positives obtained on a reversal cinematograph film for different times of the first development, indicated on the left or on top of the individual curves (W. Rahts and W. Schulz, 1931). Fig. 33.3 shows similar curves obtained in a developer containing a silver halide solvent and also shows the negative curve N obtained for 8 minutes development. The negative curve shows a high fog level caused by dichroic fog which is dissolved with the negative silver and thus causes no trouble.

The use of a developer containing a silver-halide solvent allows a thick emulsion layer to be used and in this way the exposure latitude

is increased considerably. An appreciable under-exposure, however, reduces both the maximum density and the tone range that can be reproduced.

535. By allowing a developer containing a solvent to act for different times on an unexposed material, which is afterwards blackened in white light, the effect of time of treatment and

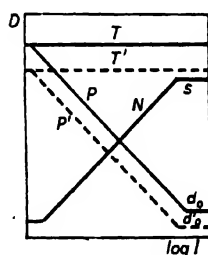


FIG. 33.1. SENSITOMETRY OF A REVERSAL MATERIAL

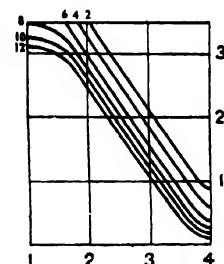


FIG. 33.2. POSITIVES OBTAINED BY VARYING THE TIME OF FIRST DEVELOPMENT

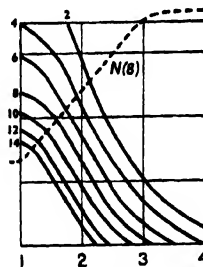


FIG. 33.3. POSITIVES OBTAINED IN A DEVELOPER CONTAINING SILVER HALIDE SOLVENT, AND CHARACTERISTIC CURVE OF NEGATIVE MATERIAL DEVELOPED FOR EIGHT MINUTES IN THE SAME DEVELOPER

concentration of the solvent can be readily demonstrated (L. Lobel, M. Dubois, and J. Vidal, 1928). They found, for example, that the addition of 2 per cent of ammonia of strength 28° Baumé decreases the total black of a positive film from 4 to 0.5 within 5 minutes at 65°F. The silver bromide is completely dissolved in 15 minutes although a solution of ammonia of identical strength but in the absence of the developer requires several hours. No similar anomaly is obtained with hypo which gives otherwise similar results. The ammonia effect is caused by the

fact that the ammoniacal silver complex is continuously reformed as the silver is precipitated on the latent image and the walls of the vessel; in this way, the solvent is regenerated all the time and does not decrease in concentration.

536. Reversal of the Residue after Controlled Dissolution of the Silver Halide. It has already been pointed out that the method of reversal of the residue is not practicable except for special thinly coated emulsions. Films or plates for additive colour photography or sub-standard cinematograph films are suitable for this method. We shall consider below the production of reversal images on paper.

Certain photographic materials are sold complete with processing rights and the user need not preoccupy himself with the details of the processing, which is carried out by the manufacturer. Detailed instructions are given with other materials, and since emulsions vary widely and display their own special characteristics, we can only recommend the user to follow in detail the processing instructions, in particular in respect to the first development.

537. Methods of Dissolving the First Negative Image. From the various possible silver solvents, as a rule an acid permanganate solution is recommended but frequently also an acid dichromate solution is used. The latent image which is not developed in the first developer is completely destroyed by acid permanganate at the usual times of treatment and concentration. With acid dichromate, on the other hand, a very feeble image persists even after several hours' treatment (G. W. W. Stevens, 1939). Acid permanganate is thus superior for the purpose, since it stops any residual negative image from interfering with the reversed positive image.

Reversal using a sulphuric acid-dichromate bath causes an appreciable tanning of the gelatine layer, whereas acid permanganate softens the gelatine. It should not be used at temperatures above 77°F, and above 68°F the concentration should be halved, in order to avoid the gelatine being dissolved or stripped from the support.

Some workers maintain that the use of a dichromate bleach decreases the contrast whereas others report the opposite result. One would conclude that this effect cannot be very great. It has been suggested that the advantages of both bleaching agents may be combined if used together. A bleach-bath often used is mixed immediately before use from stock solutions of

0.4 per cent potassium permanganate and a 1 in 50 solution of concentrated sulphuric acid in water (20 ml or 35 g of acid, and water to make 1 litre). The individual stock solutions keep indefinitely.

After the first development, the material is briefly rinsed and put into the bleach-bath. With the method of reversal of the residue, all operations bar the first can be carried out in white light. When all the silver has been dissolved, the material is briefly rinsed and transferred to a solution of 5 or 10 per cent bisulphite, which acts as a clearing bath by dissolving the manganese dioxide formed in the gelatine and the silver chloride formed from the chloride ions introduced with the wash-water. The clearing bath also restores some of the sensitivity of the silver halide lost in the bleach-bath. If at this stage any traces of the original negative image should be noticed, the procedure of rinsing, bleaching, rinsing, and clearing should be repeated.

If an appreciable quantity of silver bromide is found to persist in the high-lights, it is feasible to treat the negative in a very dilute hypo solution (approximately 1 per cent), stopping the treatment by passing the negative into a large volume of water just before the high-lights become completely transparent.

The following details on the chemical treatments may be useful. Potassium permanganate occurs in the form of small dark violet crystals with reddish brown reflections. It is sparsely soluble in cold water (6 per cent at 15°C). The solutions are also dark violet in colour, and it is therefore difficult to ascertain whether the salt is completely dissolved. It is better to use lukewarm water to dissolve the salt. Both the dry substance and its solution keep well. Permanganate causes a brown stain with organic substances by the precipitation of manganese hydroxide $[\text{Mn}(\text{OH})_2]$. The stain can be removed easily by sodium bisulphite or oxalic acid. In the preparation of sulphuric acid solutions of permanganate, one must never pour concentrated acid into the permanganate solution or on to the dry salt, since this would cause a reaction of explosive violence. K. C. D. Hickman (1930) has recommended for the sulphuric acid to be replaced by an equal volume of a syrupy solution of concentrated phosphoric acid; the mixture is said to be stable.

Where the negative image is bleached in an acid dichromate solution, the clearing bath should be a neutral sulphite solution.

538. Blackening of the Reversal Image. When the original negative has been bleached, cleared, and briefly rinsed, the residual silver bromide can be developed in any developer in room light, or after a uniform exposure to light, or finally, after treatment in a fogging agent. In order to avoid the risk of physical damage to the gelatine which might result from the alternate use of acid and alkaline solutions, an acid hydrosulphite developer might be used (§ 403). The rate of development will then be highest in the highlight regions (M. Abribat, 1930).

As a fogging agent, a dilute solution of thio-urea might be used (§ 502); this chemical can be added to the clearing bath, thus reducing the number of operations necessary.

Development should be carried on until examination from the back shows that all the silver bromide present has been reduced. This is followed by a brief wash, no fixation being required.

Development of the residual silver bromide is often replaced by transformation to a coloured substance, such as the brown silver sulphide, under conditions to be described below (§§ 738-9).

When examining critically the resulting reversal image, one should take into account that any changes in the operations will produce very different effects on a negative and on the positive obtained from it by the reversal technique. Thus a patch of fog in the negative causes a clear patch in the positive; a thin positive results from over-exposure or negative development which was too much prolonged; and a very dense image even in the high-lights is the consequence of under-exposure or under-development of the negative.

539. Reversal Methods for Paper. There are on the market several kinds of silver bromide papers specially manufactured to yield reversed pictures, especially for automatic portrait machinery, or for document copying. The processing instructions of the manufacturers should be strictly followed.

Excellent results can be obtained, however, on papers designed for negative-positive work, especially for the production of enlarged nega-

tives without an intermediate positive. The procedures are not widely different, whether the picture is to be viewed by reflection (positive) or by transmission (negative).

When positive images to be viewed by reflection are to be produced, certain sensitometric peculiarities have to be taken into account. The tone range for a picture viewed by reflection is much reduced compared with that for a transparency (§ 599). From the moment when the image viewed by reflection reaches its maximum gamma, which happens very quickly, the characteristic curve maintains its shape and merely moves bodily along the exposure axis towards smaller values of the exposure. Thus, viewed by reflection, the gamma of a reversed image is practically identical with that of a non-reversed image on the same paper.

With most positive papers carrying emulsions which are not too heavily hardened, satisfactory results are in general obtained by adopting an exposure which is two or three times as heavy as for ordinary printing. Development might be 15 to 30 times as long as for normal use. There is no need for agitation, except for the first few seconds, as long as the paper is covered by at least a quarter of an inch of solution. The picture will then be black all over, the less dense regions appearing dark grey.

After washing in several changes of water, the sheet is treated in acid permanganate until the silver is just dissolved, rinsed, cleared, and washed again until all traces of stain disappear.

If a wet sheet of paper is exposed uniformly to light, a patchy result is obtained, since the local variations in the thickness of the water layer causes the light to be refracted. It is thus necessary for the second exposure to be carried out on dry paper. Development or blackening (sulphiding, etc.) may then be carried out.

This method, described by G. Schweitzer (1935) has found very widespread application. We recommend that a sensitometric step tablet be used, when first setting up the method, with the material it is proposed to adopt.

In § 883 another method will be described which is based on a completely different principle.

CHAPTER XXXIV

METHODS OF AFTER-TREATMENT: INTENSIFICATION, REDUCTION, WORKING-UP, RETOUCHING

540. General Considerations. Of the various corrective operations described in this chapter, intensification and reduction are purely chemical manipulations, whilst the others, retouching, etc. (including the local application of intensifiers and reducers), are processes requiring manual skill, and presuppose some artistic knowledge (ideas of values and ability to draw, knowledge of anatomy for those who are concerned with portrait retouching) and the mastery of a special technique (reversal of tone values). We propose to deal chiefly with chemical methods here, because retouching, properly called, cannot very well be taught from a book.

Under the name of intensification are included all processes which, after the negative has been made, allow of increasing the various densities of the image in such a way that the difference between the extreme densities is increased, and as a result the contrast. When the densities of a negative are increased by an amount which is proportional to the original negative densities, the process is called *proportional intensification* (Fig. 34.1). When the higher densities are increased in higher proportion than the lower, the intensification is called *super-proportional* (Fig. 34.2). In the case where the lower densities only are increased *sub-proportional* (Fig. 34.3) intensification results. On the other hand, reduction comprises all methods which allow of decreasing the different densities of a photographic image with or without decreasing the difference between extreme densities.

Intensification and reduction were operations of great importance in former days when, in the absence of the great variety of printing papers available at the present time, all negatives had to have almost the same density range. In addition the shadow portions of the negative were almost completely transparent so that printing exposure times, to daylight, already long, should not become excessive. Intensification and reduction are now the exception and not the rule.

Whilst intensification, as suitably carried out on a negative which has been properly fixed and washed is an operation which does not entail

much risk, the same cannot be said for reduction, in which there is always an element of uncertainty, especially when it is applied to an already dried negative. Moreover, in the case of very dense negatives, such as result from long exposure and normal development, it is often better to confine oneself to using a more intense light for printing, or a longer time of exposure, rather than to risk the destruction of the scale of tones by reduction.

The intensification or reduction of film negatives which have a coating of gelatine on the back often leads to local stains, which occur in the gelatine backing. They are due to insufficient washing. When this occurs the gelatine backing may be removed (§ 584).

In the case of a negative having a very great scientific or documentary value, it is usual to refrain, even in the most extreme cases, from all attempts at direct improvement. Instead, a positive transparency is made from the negative under the best possible conditions; on this positive any intensification or reducing which may be necessary is carried out, and then a reproduction, forming an improved duplicate of the original negative, is printed. By taking the precautions necessary to preserve the sharpness of the image in the course of successive printings, and by choosing for each one of the printings an appropriate method (§ 712), it is possible to obtain from a very mediocre negative, without any corrective operation whatever, a very satisfactory reproduction, in which the contrast is increased or diminished to the desired degree.

INTENSIFICATION

541. Optical Intensification. When a negative is placed with its emulsion side in close contact with a good white paper or opal glass surface, the weak shadow densities appear considerably increased compared with the higher densities. There is a limit to the maximum density measured by reflected light, while the density measured by transmitted light can increase indefinitely. Full advantage has not been taken of this procedure by which, under suitable

conditions, a mediocre negative can yield a positive transparency from which a copy negative of good quality can be produced.

The increase in contrast may be offset to some extent by diffusion and reflection of the incident light. Because of this, it has been suggested that the white background should be replaced by a green fluorescent screen which can be excited by the near ultra-violet light transmitted by a Wood's filter. The small amount of blue

Properly conducted intensification may be made to give the same results as would have been obtained by prolonging development; it can even give better results, for example, when it is feared that, after a certain stage of development, fog may develop more rapidly than the image itself. As would be expected nearly all processes of intensification give increased granularity of the image.

In general, intensification should increase the

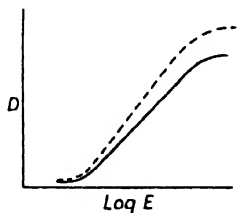


FIG. 34.1. CHARACTERISTIC CURVE SHOWING THE ACTION OF A PROPORTIONAL INTENSIFIER

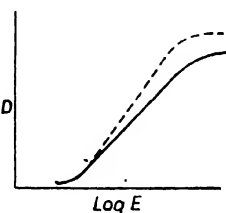


FIG. 34.2. CHARACTERISTIC CURVES SHOWING THE ACTION OF A SUPER-PROPORTIONAL INTENSIFIER

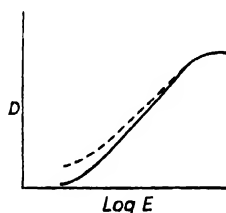


FIG. 34.3. CHARACTERISTIC CURVE SHOWING THE ACTION OF A SUB-PROPORTIONAL INTENSIFIER

and ultra-violet radiation which may be scattered is absorbed by a yellow filter, the reproduction being made on orthochromatic or panchromatic sensitive materials (H. Lewin, 1935).

Under certain circumstances good results can be obtained by combining one or more transparencies made from the same negative with the original and exposing the combination to a parallel beam of light.

A negative can be optically intensified by combining it with a thin sheet of Cellophane, sensitized with diazo compounds, on which a copy of the negative has been made by contact and developed dry (H. Ravel and F. Luhtenstein, 1929). A similar technique but using a positive transparency in contact with the negative gives the effect of proportional reduction.

542. Choice of Method of Intensification. The method which, unfortunately, is generally employed (bleaching the image in mercuric chloride and blackening with ammonia) has contributed not a little to the discredit of intensification; it destroys the details of the shadows and blocks up the high-lights; in addition, a negative intensified by this method is very unstable, the image gradually fading without the possibility of renewing it by any method whatever. Fortunately, it is very far from true to say that all methods of intensification merit this discredit.

densities of a negative proportionally. In certain circumstances, as with under-exposed negatives, it may be desirable to intensify the lowest densities to a greater extent. This can be done by means of a silver intensifier (§ 351). One should mistrust intensifiers which yield negatives which are "too clean"; the extreme clearness of the intensified negative shows that the fog has not been intensified and consequently the shadow tones also have not been increased, in spite of the fact that it is precisely these parts of the image which generally are in greatest need of intensification. The use of such an intensifier should therefore be confined solely to black and white subjects, that is to say, to copies of pen-and-ink drawings or similar originals.

It is essential that the intensified image should be as stable as the original negative. Finally, it is an advantage if the intensified image can be further intensified or reduced at pleasure, if the optimum condition has been passed.

It may be added that the eye is a very bad judge of the effectiveness of a method of intensification, and that visual methods of photometry fail when the image is not quite neutral (L. P. Clerc, 1912). Thus, for example, the application to a photographic negative of one of the treatments, which will be described later under the name of "sulphide toning," gives

an image which is less vigorous according to visual examination, but the effective contrast is augmented for printing purposes (A. H. Nietz and K. Huse, 1918).

We recommend the photographer who wishes to determine for himself the effectiveness of an intensifier to intensify half of a spare negative, and to print *separately* on the same paper the best possible print of each half, comparison being made on the prints.

In spite of the great variety in the methods of intensification, there are fairly narrow limits in the choice of a method giving the best result in a given case.

The amateur photographer will, as a rule, prefer methods by which intensification is brought about in a single operation (mercuric iodide intensifier), which makes control easier, or those methods which do not require the use of poisonous materials (chromium intensifier).

The photographer using miniature negatives is limited to those methods of intensification which give no increase in granularity.

The physicist will prefer, in certain cases, the only method yielding exact proportionality between densities before and after intensification together with perfect stability of the image (negative bleached with mercuric chloride and then blackened with ferrous oxalate).

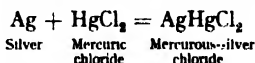
The maker of black-and-white line reproductions has often no interest, indeed sometimes just the opposite, in preserving the tones of the negative, especially when these tones are only due to slight spots or to inequalities of illumination of the original and are frequently removed before intensification by means of superficial reduction. He is therefore only concerned with the increase of contrast. The negative, bleached in mercuric chloride, is blackened by ammonia if only moderate intensification is required and if the negative need not be preserved; or in silver cyanide, if considerable intensification is sought.

Lastly, those methods which give great intensification are specially useful in saving negatives which have only a faint trace of image and which cannot be replaced under better conditions.

The use of mercury intensifiers is to be avoided for very small negatives which require considerable enlargement, because the graininess is often very much increased. A negative or positive which is to be preserved should not be treated with a salt of mercury unless subsequent treatment is given, which reduces the mercury to the metallic state, or to the state of sulphide; in

any other case the image is certain to be destroyed after a more or less prolonged period.

543. Mercury Intensification in Two Successive Baths. When a negative, in which the image is almost wholly metallic silver, is treated in a solution of mercuric chloride,¹ the silver is converted into a double mercurous-silver chloride, a complex white salt having properties which are slightly different from those of a simple mixture of silver chloride and mercurous chloride or calomel. The chemical reaction is represented by the equation



In this way the silver adds to itself about double its weight of mercury (200 parts of mercury to 108 parts of silver). At this stage of the operation there is exact proportionality between the original density and the new density, the latter being considerably less than the original density.

As a rule, a solution is used containing about 30 g mercuric chloride and 5 ml hydrochloric or nitric acid in 1,000 ml. Such a solution hardly deteriorates at all on keeping; used solutions may be kept for further use until the active substance is exhausted.

The presence of traces of sodium or silver thiosulphate in the negative due to incomplete washing causes the formation of opalescent patches or spots.

During the first few moments in the bath the image darkens, and by transmitted light shows a violet tint; it then gradually becomes

¹ Mercuric chloride, commonly known as *bichloride of mercury* or *corrosive sublimate*, is a colourless salt, crystallizing in needles, though it is generally sold in pieces of fibrous appearance. It is very dense (specific gravity 5.4), and is not very soluble in pure water (about 7 per cent at 60°F); in warm water its solubility is greater. It is volatile and is carried over in the steam from a boiling solution. Its solubility is increased by the presence of acid or of ammonium chloride. It is very soluble in alcohol. Mercuric chloride, like all other salts of mercury, is a poison which may be sold over the counter by registered dispensing chemists only; its solutions should not be allowed to touch the skin if the latter is broken. Mercury salts as a group attack many metals (gold, silver, copper, etc.), which are thus amalgamated. Aluminium is strongly attacked by it, yielding thread-like deposits of alumina. Solutions of mercury salts must not be allowed to touch any metals, especially jewellery, and for this reason rings must be taken off, and watches must not be touched by fingers moistened with these solutions. In the case of a neutral solution, a small amount of mercuric chloride is uniformly retained by the gelatine of negatives which have been bathed in it.

white. For proportional intensification the treatment is continued until the image, when viewed from the back, is seen to be completely whitened. In the case of a hard negative in which it is desired to intensify the parts of least density (sub-proportional intensification) the action of the mercuric chloride may be interrupted before the heavier densities are completely bleached.

After it has been removed from the bleaching bath the negative must be washed in several changes of water before being darkened. This washing should preferably be done with water slightly acidified with hydrochloric acid, in order to dissolve the mercuric chloride retained by the gelatine.

The layer of gelatine being often very rough after treatment with mercuric chloride, any abrasion on the image, or a strong jet of water, can cause tears that after blackening show as pin-holes. Similar careful washing must also be carried out after darkening by any of the processes now to be described.

544. Darkening with Ammonia. The image, bleached and washed as described above, turns brown and then black almost instantly when it is placed in a very dilute solution of ammonia (30 ml per litre). The greater part of the silver chloride in the image is dissolved by the ammonia and takes with it an appreciable amount of the mercury, whilst the residual mercuric salt is converted into a black substance which is very opaque but not very stable. The mercurous chloramide thus formed has the formula $\text{Hg}_2\text{H}_2\text{NCl}$.

The optical density is multiplied by a factor varying from 1.4 to 1.7 in the denser parts of the image, the higher values of this factor corresponding generally with the use of a dilute solution of ammonia in which the negative has been allowed to remain for a time only sufficient just to blacken the image throughout its thickness. If the image fades after such intensification it cannot be regenerated.

The ammonia solution employed for blackening each negative must be thrown away after use.

As we have already noted, this method of intensification, which is not suitable for negatives with grey tones nor for those to be kept, reduces the clear tones (or at any rate does not intensify them) whilst it strengthens the heavy densities.

Transfer from a very acid bath to an alkaline bath often causes numerous markings and some-

times reticulation of the gelatine; it has been recommended, in order to diminish the liability to these defects, to avoid all rubbing of the film during and after its treatment with ammonia, and to add alum (about 3 per cent) to the solution of mercuric chloride.

545. Darkening with Sodium Sulphite. A considerable improvement in the mercury intensification process is made by using sodium sulphite (C. Scolik, 1884) instead of ammonia for darkening the image.

The image darkens almost instantly in a solution of sodium sulphite. Half of the silver is found in the darkened image, together with a quarter of the mercury which was associated with it, both metals being for the most part reduced to the metallic condition (Chapman Jones, 1894), whilst the other half of the silver and three-quarters of the mercury go into solution as complex sulphites. Secondary reactions also slowly occur between the metals in the image and in the solution, if the contact is maintained; there is a deposition of silver, which is to some extent added to the image, and to some extent replaces part of the mercury. The presence of a small amount of silver chloride in the image can be demonstrated (as also in the case of images darkened by ammonia) by the fact that the densities are slightly decreased when the negative is placed in a solution of sodium thiosulphate.

As a rule, a solution of about 5 per cent of anhydrous sodium sulphite (or 10 per cent of crystallized sulphite) is employed in a slightly acid condition; the acidification is effected by the addition of sodium bisulphite or of an acid. Solutions which have been used must be thrown away after treatment of each negative.

The intensification becomes a little more energetic if, instead of converting the image into the mercurous-silver chloride, it is converted into the corresponding bromide. This may be done by bleaching in a solution containing equal weights of mercuric chloride and potassium bromide (30 g of each, dissolved separately in 500 ml of water, then mixed). In addition, some of the irregularities of intensification are diminished, due to the fact that silver bromide is much less soluble than the chloride in solutions of sodium sulphite.

Whilst, after bleaching in mercuric chloride, the factor of the increase of densities for an image darkened in sulphite ranges from 1.0 to 1.2 when one goes from low densities to high, these values increase to between 1.2 and 1.6

when the negative is bleached with mercuric bromide (or in a mixture of equivalent amounts of mercuric chloride and potassium bromide).

In either case the intensified image is quite stable.

546. Darkening with Ferrous Oxalate. By means of a ferrous oxalate developer (§ 402), an image which has been bleached in mercuric chloride is reduced completely to the metallic condition without exposure to light being necessary. This process is so exact that satisfactory photometric measurements may be made of the lower densities after intensification, the proportionality factor for the increase of density being applied. If the gelatine is hardened and other suitable precautions are taken, including intermediate washing, the whole set of operations (bleaching and blackening) may be repeated as many times as desired, the densities and contrast increasing each time with exact proportionality. The factor for growth of density is 1.45 for each intensification. The developer may be used several times over.

This method of intensification is only to be recommended for certain scientific applications of photography.

547. Darkening with an Organic Developer. Common developing solutions are capable of darkening images which have been bleached in mercuric chloride or bromide. Due to the chemical reducing action of the developer, the greater part of the metals which would be dissolved in solution of pure sulphite is reduced to the metallic condition, though the reduction is never complete. As mentioned previously and for the reasons already given, it is advantageous to use mercuric bromide for bleaching. Amidol, whilst it is far from giving the greatest intensification, gives very satisfactory proportionality between the densities before and after intensification. The value of the proportionality factor is about 1.18.

Whatever the developing agent, each portion of the solution should be used once only.

548. Various Other Methods of Darkening. A great number of reagents have been suggested for darkening images bleached in mercuric chloride; sodium thiosulphate gives only a negligible intensification, except for the accidental formation of sulphide which generally occurs as stains in the lighter parts of the image. Sodium sulphide is very largely employed for blackening intensified images on wet collodion plates, and in such circumstances gives excellent results; its application to gelatine bromide plates is,

however, dangerous, because of the intense fog which appears if a little of the mercuric chloride has been retained by the gelatine. Other solutions which may be mentioned as capable of giving strong intensification are as follows: a very dilute solution of caustic soda, to which formalin has been added (Blake-Smith, 1901), a solution of stannous tartrate prepared when required for use by dissolving a little stannous chloride in a dilute solution of tartaric acid (Hélain, 1901) and many other substances which are reducing agents in the chemical sense.

Special mention should be made of the process of darkening by means of silver cyanide (D. van Monckhoven, 1879), which is frequently used commercially in the copying of originals, since it reduces the lower densities (fog, etc.) at the same time that it increases the higher densities considerably. The darkening solution may be prepared by dissolving 25 g of silver nitrate in about 500 ml of water and adding in small quantities at a time a solution of 20 g of pure sodium or potassium cyanide in about 200 ml of water until the precipitate first formed is almost entirely redissolved. The volume is then made up to 1,000 ml with water. The solution may be used several times over.

549. Single-solution Mercuric-iodide Intensifier. Intensification in a single solution of mercuric iodide was described in 1879 by B. J. Edwards. Since mercuric iodide (or bi-iodide of mercury, a very heavy red salt, generally supplied in the form of powder) is insoluble in water, this author proposed dissolving it in a mixture of potassium iodide and of sodium thiosulphate (in each of which it is separately soluble). Later, it was found (Lumière and Seyewetz, 1899) that the use of sulphite instead of thiosulphate permits a slightly more vigorous intensification. Whilst a negative which has been fixed in a fresh bath may be thus intensified after very brief washing, a yellow fog will result, due to precipitation of silver iodide, if the negative has been fixed in a bath containing much silver salt and is badly washed.

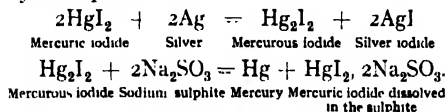
The following baths are used—

	I Edwards	II Lumière and Seyewetz
Potassium iodide	20 g	—
Sodium sulphate, anhydrous	—	100 g
Mercuric iodide	20 g	10 g
Sodium thiosulphate	20 g	—
Water to make	1000 ml	1000 ml

The first of these solutions contains no oxidizable product, and is more stable than the second. Both can be kept for a long time in the

dark (earthenware bottles or glass bottles covered with black paper). The solutions may be used many times so long as they are kept away from light when not in actual use.

In these baths the image is intensified progressively without changing its appearance; the silver is converted into iodide, whilst at the same time metallic mercury is deposited on it. It seems that the series of reactions occurring in this intensification process may be represented by the equations—



The process is stopped when the desired degree of intensification has been obtained; the negative is then thoroughly washed.

The image intensified by the first of these methods is slightly more stable than that intensified by the second.

In moist air, though more slowly in dry, an image intensified in this way becomes yellowish (probably due to the formation of a complex of mercuric oxide and silver iodide). Absolute stability can be conferred on the image by placing the negative, after washing, in an ordinary developing bath, which reduces the silver iodide to metallic silver, or in a 1 per cent solution of sodium sulphide (§ 738) which changes the two metals into sulphide without appreciably modifying the densities of the image.

A negative, which for the lack of these precautions has suffered this alteration of colour, may at any time be brought back to its original condition after intensification by treating it for a sufficient time with a developer or with the sulphide solution.

The action of this intensifier is not proportional (Nietz and Huse, 1918); the action is greatest with the lower densities, which is a considerable advantage in most cases of practical interest, the shadow parts of a negative requiring more energetic intensification than the image of the high-lights. The lowest densities are approximately doubled whilst the higher densities are multiplied by about 1.4.

Altogether the mercuric iodide intensifier is one of the most general usefulness. Especially for the purposes of Press photographers, who often need to give a little sparkle to negatives, it has the very great advantage that there is no need for the very long washing for removal of hypo which is required when using most other

intensifiers. The possibility of a subsequent change in the negative is often a matter of no importance.

A single solution of mercuric sulphocyanide has been suggested as an intensifier (Andresen and Leupold, 1899), but, after intensification, the image tends to bleach if it is allowed to remain in the bath; this can, however, be remedied by treatment with a developer.

550. Chromium Intensification. About 1880 Eder suggested as a possible method of intensification the conversion of the silver of the photographic image into silver chloride by means of a solution of bichromate acidified with a little hydrochloric acid, and its re-development in a pyrogallol developer. In this way, in addition to the black image of the reduced silver, there is superimposed on it the brown image which is formed in the gelatine by the oxidation products of the pyrogallol.

In experimenting with this process, which had been forgotten, C. Welborne Piper and D. J. Carnegie in 1904 found that the intensification was partly due to the deposition of a chromium compound (probably the oxide) in the image, the amount of this deposit being greater if the bleaching solution were only slightly acidified. The active agent in this intensification appeared to them to be a *chlorochromate* (produced by the action of hydrochloric acid on a bichromate), and they found that the silver chloride thus formed was developable without exposure to light, at any rate if the bleaching bath did not contain a great excess of hydrochloric acid; the latter, by being partially converted to chlorine, yielded ordinary silver chloride, which was only developable after exposure to light. For darkening they recommended the use of an amidol developer as lending itself best to the purpose of successive intensifications without causing frilling of the gelatine. The progressive increase of density by repeated intensification has been confirmed by photo-micrographs published in 1916 by W. T. P. Cunningham.

It has been shown that the mixture of bichromate and hydrochloric acid may be replaced by a pure solution of a chlorochromate (Lumière and Seyewetz, 1919), or by mixtures of chromic acid with a chloride (C. H. Bothamley, 1918), or of a bromide (L. J. Buncle, 1923).

Lumière and Seyewetz consider that, on bleaching, only half of the silver is converted into developable silver chloride, the other half forming a double chromite of silver and potassium, a brown insoluble compound which would

not be acted on by a developer. In this way may be explained the increasing brown coloration of images which have been successively intensified, as also the decreasing magnitude of the effect of re-repeated treatments.

For the practical application of this method of intensification two stock solutions are prepared. These by themselves will keep indefinitely—

(A) 10 per cent solution of potassium bichromate.

(B) Ordinary hydrochloric acid diluted to ten times its volume with boiled water.

If it is required to obtain varying degrees of intensification, heavy, medium or slight, one of the following mixtures must be made up at the time required—

Intensification	Strong	Medium	Slight
Solution A	10	20	20
Solution B	2	10	40
Boiled water to make	100	100	100

The effect of any of these mixtures, given here only as an approximate indication, varies very much with the nature of the emulsion on which the image is obtained. With some plates the solutions recommended for weak intensification give quite a heavy effect, and in such cases the amount of hydrochloric acid must be adjusted. The amount of acid prescribed for strong intensification may be very much too small if the water employed contains much calcium bicarbonate.

The various operations in intensification must be carried out in weak daylight or in artificial light in order to avoid solarization of the silver chloride. The negative is allowed to remain in the bleaching bath until all traces of black image have disappeared when viewed from the back, but it should not be allowed to remain in this bath for a longer time than is necessary, otherwise irregular markings are likely to be produced.

Negatives must be washed in several changes of water until the coloration of the gelatine has almost completely disappeared. The washing process may be considerably shortened by immersing the negatives, after rinsing, in a solution containing about 5 per cent of sodium carbonate.

The image is then re-developed, preferably in a metol-hydroquinone developer. In case the bichromate is incompletely eliminated (which is possible even after prolonged washing) using an amidol developer risks the formation of insoluble oxidation products resulting in the formation of red spots (W. A. Ermen, 1928). In some developers the image comes up very rapidly at first and then appears not to change, though in reality it increases slowly for at least a quarter of an hour.

If the intensification is thought to be insufficient it may be repeated; there is, however, very little to be gained by intensifying more than twice. The factor of proportionality attains successively the following values in the case of several successive intensifications, re-development being effected in a metol-hydroquinone developer which is only very slightly alkaline (P. E. Boucher, 1935)—

Number of intensifications .	1	2	3
Factor	1.4	1.65	1.8

Images intensified in this way are quite permanent; their warm black tone renders the method very suitable for the intensification of lantern slides or paper prints, either for the purpose of intensification as such or, by slightly increasing the amount of acid, to improve the colour. It may be noted that this method of intensification, which, incidentally, does not make use of any poisonous substance, is extremely economical.

The only objection which may be raised against this method of intensification is that it gives to the gelatine of some emulsions a granular structure which makes retouching difficult, though it does not show on printing either by contact or on enlarging.

The sensitometric measurements of Nietz and Huse (1918) have shown that, contrary to conclusions drawn from photometric measurements, the action of this intensifier is not proportional, but is greater in the least dense regions, a property which we have already seen to be very valuable.

551. Heavy Intensification with Copper and Silver. A method which has been used for a very long time, especially for collodion negatives, consists in treating the negative in a solution of cupric bromide in which the silver is converted into bromide and at the same time fixes an equivalent amount of cuprous bromide.

The negative, after rinsing, is transferred to a solution of silver nitrate, some of which is reduced to metallic silver by the cuprous bromide; this silver is thus precipitated with an equivalent amount of silver bromide in the image along with the existing silver bromide. After washing, and reducing the silver bromide, the amount of silver is exactly three times that originally present (Abney, 1877). This method is not easily applicable to negatives made with gelatine-bromide emulsions; during washing, which is much slower than with collodion plates, the cuprous bromide is partially re-dissolved or re-oxidized and so escapes reaction.

The method has been improved by Luther and Schreiber (1923), and by G. Zelger (1924), by using in the first operation a solution which deposits in the image not cuprous bromide but a cuprous salt which is absolutely insoluble and non-oxidizable, such as cuprous sulphocyanide or cuprous iodide.

As before, the density is exactly trebled by intensification; it may be again trebled by repeating the process, and thus sufficient contrast may be obtained to print an image which exists as a mere ghost, as is sometimes obtained with films in which regression of the latent image has occurred.

Care must be taken to avoid uneven action or reticulation of the gelatine if the process is repeated more than once.

The "bleaching" bath (which, as a matter of fact, gives a yellow image) is prepared by pouring solution (A) into solution (B)—

Copper sulphate, cryst . . .	5 g
Acetic acid, glacial . . .	28 ml
Water to make . . .	500 ml

Potassium iodide . . .	5 g
Ammonia (22° Baumé) . . .	46 ml
Water to make . . .	250 ml

Heat is generated when the solutions are mixed, and the bath must not be used until cool. The mixed solution, which is clear blue in colour, should be slightly acid; if it is not, a little acetic acid must be added until blue litmus paper is faintly reddened by it. This solution is quite stable and may be used until exhausted.

The negative is immersed in it until the image becomes yellow throughout its thickness. After thorough washing it is blackened in a solution containing 0.25 per cent of silver nitrate to which about 1 per cent of sodium acetate has been

added (so preventing the copper nitrate formed during the reaction from attacking the silver). Before treatment with silver nitrate, the negative may be immersed in a saturated solution of alum, so preventing combination of silver nitrate with the gelatine.

The silver salts, other than silver iodide (chloride precipitated in the gelatine due to the use of ordinary water and silver nitrate combined with the gelatine), are removed by immersion for about two minutes in a bath containing about 1 per cent of ammonia, which has no action on silver iodide.

The process is completed by reducing the silver iodide to the metallic state by means of a solution of sodium hydrosulphite containing a little sodium bisulphite, or by means of an amidol developer made alkaline with sodium carbonate.

552. Quinone Thiosulphate Intensifier. This is a single solution intensifier specially recommended for under-exposed or excessively thin negatives. It was introduced by Muehler and Crabtree (1945) and produces a greater degree of intensification than any other known single solution intensifier, particularly when used for high-speed materials. The following solutions are required—

(A) Water (70°F) . . .	750 ml
Sulphuric acid (conc.) . . .	30 ml
Potassium bichromate . . .	22.5 g
Water to make . . .	1000 ml
(B) Water (70°F) . . .	750 ml
Sodium bisulphite . . .	3.8 g
Hydroquinone . . .	15.0 g
Wetting agent (10 per cent solution) . . .	20 ml
Water to make . . .	1000 ml
(C) Water (70°F) . . .	750 ml
Sodium thiosulphate (cryst.) . . .	22.5 g
Water to make . . .	1000 ml

If kept in stoppered bottles Solution A is stable indefinitely while solutions B and C are stable for several months. Solution B should be re-mixed whenever it becomes appreciably coloured as a result of oxidation and solution C should be discarded if a precipitate forms indicating sulphurization.

For Use. To one part of Solution A, with stirring, add two parts of Solution B, then two parts of Solution C. Continue stirring and finally add one part of Solution A. The order of mixing is important and should be adhered to.

Negatives should be washed for 5-10 minutes and hardened in the following alkaline formaldehyde hardener for 5 minutes at 68°F and then washed for 5 minutes.

Water	500 ml
Formaldehyde (40 per cent solution)	10 ml
Sodium Carbonate (anhydrous)	5 g
Water to make	1000 ml

After hardening, immerse in the intensifier with frequent agitation to avoid streaking. When working in a dish treat only one negative at a time. The intensifier should be freshly mixed and used only once. Maximum intensification is given in about 10 minutes at 68°F. Then washing for 10 to 20 minutes is followed by drying as usual. Lower degrees of intensification can be obtained by treatment for shorter times.

This intensifier is unique in that the greatest intensification is obtained on the images of relatively coarse-grained emulsions (medium and high speed) while very fine grained materials are intensified to a negligible degree. A maximum photographic intensification of the order of 10 times and a significant increase in apparent emulsion speed can be obtained. Traces of chloride in the water used for preparing the intensifier solutions have a great effect on the course of intensification, causing a progressive decrease in the degree of intensification as the concentration of chloride ion increases upwards from about 15 parts per million. Thus it is advisable to use distilled water. The intensified image has a brown tone and is not indefinitely permanent, but under normal conditions of storage should be stable for at least 5 years. The intensified image is destroyed by acid hypo, so under no circumstances should the intensified negative be placed in fixing baths or wash-water contaminated with fixing bath.

Negatives which have received the maximum degree of intensification are appreciably grainy; this is not unexpected since graininess is known to increase with increase in gamma and also since maximum intensification takes place in the densities where the greater proportion of the too large grains occurs.

553. Other Methods of Intensification. The methods of intensification described in the preceding paragraphs are amply sufficient for all practical requirements, so that we shall be content to mention only briefly some others which are sometimes used, or which are in themselves curious because of the means employed.

R. B. Wilsey (1919) showed that intensification by means of pyro provides a means for increasing almost indefinitely the contrast of a negative while preserving very fair proportionality between the effective final and the initial

densities. This is done by successive bleaching and re-development of the image, using a pyrogallol developer containing only a small amount of sulphite—

BLEACHING

Potassium ferricyanide	30 g
Potassium bromide	10 g
Water to make	1000 ml

RE-DEVELOPMENT

Sodium sulphite, anhydrous	10 g
Pyro	5 g
Sodium carbonate, anhydrous	10 g
Water to make	1000 ml

The bleaching bath keeps for a long time, even if used, but the re-development bath should be made up in small quantities and used only once.

The factor for the increase of density and contrast has the following successive values in the case of a negative developed originally in metol-hydroquinone.

Number of Intensifications	1	2	3	4	5
Factor	1.70	2.10	2.40	2.65	2.80

On the other hand, a negative which has been developed in pyro (or intensified by the above method) may be reduced proportionally by bleaching it in a solution of permanganate acidified with hydrochloric acid (§ 513) and re-developing it in any developer which yields a black image.

Intensification by precipitation of silver according to the method already described for physical development before or after fixing (§§ 484 and 486) is especially suitable for fine-grained images. It is often an advantage to precede this process by immersion in a very dilute solution of permanganate acidified with sulphuric acid (the reversal bath described in § 537 diluted twenty or fifty times with water), and to follow it by treatment with sodium thiosulphate. (This method of intensification may be carried out *before* fixation.)

The granularity of a negative can be reduced without appreciably increasing its contrast by applying a variation of blackening by sodium sulphide suggested by P. Strauss (1940). This is in fact toning the image (§ 738). The silver image is converted to silver bromide by treatment with a ferricyanide bleach consisting of 3 per cent potassium ferricyanide, 1.5 per cent potassium bromide, and 1 per cent sodium carbonate. After bleaching, wash well and immerse in a 1 per cent sodium sulphide solution containing 0.5 to 1 per cent sodium thiosulphate. (The optimum amount must be determined by

trial for each emulsion.) The silver bromide is converted to silver sulphide and a small amount of the silver bromide is dissolved by the hypo from the surface of the grains and reprecipitated as colloidal silver sulphide near the grains. By this means the spaces between the grains are more or less filled thus reducing the apparent granularity.

A method giving great intensification but requiring rather delicate manipulation has been described by K. Hickman and W. Weyerts (1933): a sulphide-toned image (§§ 736 and 741) is placed in a solution of silver sulphide and, under the action of a strong artificial light, it progressively becomes intensified by deposition of silver. After intensification to the desired degree the image is rinsed, placed in a fixing bath and washed.

It has been suggested that a negative may be intensified by "doubling" the image in "carbon" on the gelatine of the negative by the Carbro process, or by an image obtained by dusting-on, the sensitive layer (bichromated glue) being coated on the gelatine face of the negative, which has been previously varnished. Lastly, it has been suggested that an image may be intensified by contraction of the film after detaching it from its support.

REDUCTION

554. Choice of a Reducer. The usual reducers act by gradually dissolving the silver which forms the photographic image, but widely different results are obtained according to the substance (or mixture of substances) which is used for this purpose.

Uniformity of action of a reducer is obviously only possible if it can penetrate to all parts of the image at the same speed; in the case of a dry negative, however, and particularly if fixation has been done in a bath containing alum, the permeability of the gelatine is often very different in the various parts of the image, and thus there is a great risk that the process of reduction will produce markings which cannot be removed. Traces of grease on the negative (finger-marks, etc.), even though they do not prevent the swelling of the gelatine, cause the reducer to penetrate more slowly, and so cause trouble. Where necessary, these traces of grease must be removed by cleaning with pure benzene or petroleum spirit. The addition of wetting agents (§ 459) can facilitate the uniform penetration of the reducer. If, therefore, reduction has not been carried out before drying the nega-

tive, the latter should be soaked in water until the gelatine has swollen uniformly, which will sometimes require three or four hours.

The characteristics of a reducer depend largely on the dimensions of the grains forming the image, and on the distribution of these grains in the depth of the layer; hence there are considerable variations in effect according to the type of emulsion, and even with negatives of a given emulsion developed under very different conditions.

Differences have been noticed in a given negative in the reduction of areas of equal density produced by different rays, or corresponding to latent images of different ages at the moment of development (C. Jausseran, 1933).

The various reducers may be schematically classified into three groups—

1. Subtractive reducers.
2. Proportional reducers.
3. Super-proportional reducers.

Subtractive reducers are very active solvents of silver. They attack the silver almost as fast as they penetrate the film of gelatine, so that the different densities in the image are decreased by approximately the same amount (Fig. 34.4), and if the action is allowed to go on too long some parts of the image may disappear altogether. These reducers are specially suited for the clearing of fogged negatives. They are generally chosen for local reducers in retouching.

A *proportional reducer* decreases every density in the image in the same proportion. This may be brought about by converting the silver of the image into a less absorbing substance or mixture of substances (Fig. 34.5), e.g. by blue toning (L. P. Clerc, 1899) or by iodizing the image. The removal of the same fraction of the quantity of silver at every point of the image is never realized except, approximately, by the use of solvents whose action is so slow as to be negligible during the time taken to penetrate the film of gelatine. These reducers are most suitable for diminishing the contrasts of negatives which have been over-developed.

A *super-proportional reducer* removes a greater proportion of the silver from the dense parts of a negative than from the lighter parts, as if its action started from the support of the film and moved outwards towards the surface

of the gelatine (Fig. 34.6). The only reducer known to belong to this group is ammonium persulphate; it dissolves silver slowly, and its activity is increased by the silver sulphate produced in the course of the reaction (auto-catalytic reaction).

Lastly, in certain cases, it is required to reduce only the dense parts of the negative. This may

solution of sodium thiosulphate. In this very unstable mixture, which generally loses its activity (recognized by the decoloration) in a time varying from a few minutes (mixture of highly concentrated solutions) to a few hours (mixture of very dilute solutions), the ferricyanide controls the activity of the mixture, the concentration of thiosulphate being always sufficient

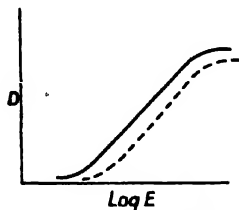


FIG. 34.4. CHARACTERISTIC CURVE SHOWING THE ACTION OF A SUBSTRACTIVE REDUCER

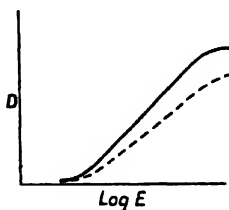


FIG. 34.5. CHARACTERISTIC CURVE SHOWING THE ACTION OF A PROPORTIONAL REDUCER

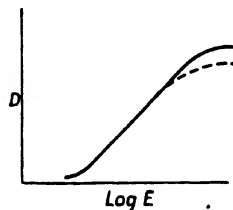


FIG. 34.6. CHARACTERISTIC CURVE SHOWING THE ACTION OF A SUPER-PROPORTIONAL REDUCER

be done indirectly by allowing the solvent of silver to act only after all the silver contained in the surface layers of the film has been converted into an insoluble compound.

In using any of the reducers of the first three groups, the negative should always be withdrawn from the bath a short time before the desired effect has been produced, because the solution of the silver continues during the first moments of washing.

555. Subtractive Reducers. Whichever of the reducers of this class may be used, anything which tends to increase the rate of solution of the silver (increase in concentration of the active substance) or to diminish the velocity of penetration into the gelatine (excessive swelling of the film, thickening of the liquid, etc.) exaggerates the peculiar character of this class of reducer. The converse tends to make these reducers behave in a proportional manner.

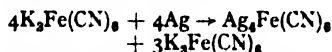
The concentrations recommended later are averages which may be increased or diminished as desired. It must, however, be borne in mind that the use of comparatively highly-concentrated reducers renders control difficult unless a glass dish, illuminated from below, is employed.

556. Farmer's Reducer. The oldest known of the subtractive reducers (H. Farmer, 1884) is a mixture (prepared when required for use) of a solution of potassium ferricyanide¹ with a

to give rapid solution of the silver salt which is formed.

The ferricyanide converts the silver to silver ferrocyanide which is dissolved by the thiosulphate if the latter is present in excess.

The reaction is as follows—



If the ferricyanide is in great excess, 15 per cent ferricyanide + 0.5 per cent anhydrous thiosulphate, an unstable solution is formed in which intensification by sulphide toning of the image may occur (Kickman and Hecker, 1934).

Practised workers, in judging how to mix the two stock solutions, are guided by the depth of colour of the mixture. At first it will be suitable to mix in equal volumes a 1 per cent solution of potassium ferricyanide and a 10 per cent solution of sodium thiosulphate.

By making the mixture alkaline with a little sodium carbonate (Stürenberg, 1903) or with ammonia (R. Namias, 1910) it will retain its

often covered with an ochre-like layer due to exposure to the air; this should be washed off before a solution is prepared. The salt is very soluble in water (solutions up to 30 per cent may be prepared in the cold); its concentrated solutions have a yellowish brown colour, whilst dilute solutions are greenish yellow. These solutions are unstable, especially in light, becoming partially converted into ferrocyanide. For this reason large quantities should not be dissolved at one time, although for use as a reducer its solutions may be stabilized by means of sodium chloride added in amount double that of the ferricyanide.

¹ Potassium ferricyanide, sometimes still called "red prussiate of potash," occurs in crystals of intense red colour having the formula $K_3Fe(CN)_6$. The crystals are

activity considerably longer and its rate of attack on the silver will be retarded a little; at the same time the somewhat persistent coloration of the gelatine by the ferricyanide will be prevented.

In order to avoid irregular action, the dish must be rocked during the whole process of reduction. The negative must be rinsed every time it is taken out of the bath for purposes of examination, otherwise streaks of lighter density may occur.

As a solvent of the silver ferrocyanide, the thiosulphate may be replaced by cyanides (*poisonous*) or by the alkaline sulphocyanates; the mixtures thus formed are very stable.

557. Permanganate Reducer. A very dilute, acidified solution of permanganate (R. Namias, 1899) behaves as a reducer. It is very economical and its action is not quite so entirely subtractive as that of Farmer's solution.

The following mixture is made up when required—

Potassium permanganate, 0.4 per cent solution	3 to 5 ml
Sulphuric acid, 2 per cent solution	3 to 5 ml
Water to make	100 ml

Instead of the water, a 2 per cent solution of alum may be used in order to avoid the softening of the gelatine in warm weather.

The silver is dissolved in the form of sulphate; a part of this is precipitated as the chloride by the chlorides present in the water used for making up the solutions or in rinsing the negative. In addition the negative becomes brown due to the manganese dioxide formed in the partial reduction of the permanganate. Both of these substances may be removed by immersing the negative in a solution containing about 10 per cent of sodium bisulphite, followed by washing in several changes of water.

558. Other Subtractive Reducers. Of the many other reducers having practically identical properties, mention may be made of those which may be kept ready for use and which can be used several times.

The following may be included in this group: a mixture of ferric oxalate, sodium sulphite, and sodium thiosulphate (Belitski, 1883), which is perfectly stable in the dark. A modified formula (J. I. Crabtree and L. E. Muehler, 1932) which remains active for about three days without special precautions, would appear to be the most perfect of superficial reducers, all the densities

being decreased by the same value (E. L. Turner and W. J. Smith, 1935)—

Ferric chloride, cryst.	25 g
Potassium citrate	75 g
Soda sulphite, anhydrous	30 g
Citric acid	30 g
Hyposulphite of soda, cryst.	200 g
Water to make	1000 ml

Also a solution of potassium bichromate acidified with sulphuric acid (10 g bichromate and 10 ml acid made up to 1,000 ml), which may be made up as a very concentrated stock solution (E. Gosselin, 1880); a solution obtained by adding to a solution of sodium thiosulphate a solution of cuprammonium sulphate which is prepared by adding ammonia to a solution of copper sulphate until the precipitate first formed is re-dissolved in a *large excess* of ammonia (Prunier and Mathet, 1892); lastly a solution containing about 5 per cent of cerium (ceric) sulphate (*poisonous*) acidified with sulphuric acid (Lumière and Seyewetz, 1900).

We may also mention, but only to advise the avoidance of its use, the possibility of reducing a negative by a very dilute solution of hypochlorite of soda (*eau de javelle*), which acts mechanically by dissolving the gelatine, so removing the surface layers of silver.

559. Proportional Reducers. Quinone Reducer. The addition of sulphuric acid to the extent of about 20 ml to 1,000 ml to a saturated solution (0.5 per cent) of benzoquinone (ordinary quinone) furnishes a reducer (Lumière and Seyewetz, 1910) which has more recently been found (R. Luther, 1923) to act almost proportionally on the various densities. This solution, which is clear yellow, gradually turns brown, and finally gives a brown deposit. An image which has been reduced in this bath acquires a slightly reddish tint. It is necessary, after reducing and brief rinsing, to bathe the negative for some time in a solution containing about 10 per cent of sodium bisulphite before proceeding to the final washing.

Ferric Sulphate Reducer. A very dilute solution of a ferric salt which is quite free from chlorides and bromides (a condition which is generally satisfied by ferric ammonium alum which is a crystalline salt of pale rose-violet colour), and which is acidified by a little sulphuric acid, forms a reducer which is almost exactly proportional in its action and keeps well (H. Krause, 1919). The solution employed may

usefully be a 2 per cent solution of the salt in rain water or distilled water containing about 0.5 per cent of pure sulphuric acid. After rinsing, the negative is bathed for some time in a very dilute solution of sulphuric acid before the final washing.

Potassium permanganate and Persulphate. A mixture in suitable proportions of the subtractive acid-potassium permanganate reducer with the super-proportional persulphate reducer forms a reducing solution of intermediate character, the action of which is almost proportional (N. C. Deck, K. Huse and A. H. Nietz, 1916).

The bath must be prepared when required for use by mixing the following substances in the order given, each one being dissolved separately in a small amount of water—

Potassium permanganate	0.10 g
Sulphuric acid (1 per cent solution)	60 ml
Ammonium persulphate	10 g
Water to make	1000 ml

The time required for reduction is from 2 to 5 minutes. The negative is then rinsed and bathed for 5 minutes in a solution containing about 10 per cent of sodium bisulphite before being washed in several changes of water.

560. Ammonium Persulphate Super-proportional Reducer. The selective action of alkali persulphates on the higher densities of photographic images was discovered in 1901 by A. and L. Lumière and A. Seyewetz, who specially recommended the use of ammonium persulphate.¹ It must, however, be stated that with negatives which have been developed with paraminophenol (and only in this case) ammonium persulphate behaves sometimes as a subtractive reducer.

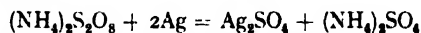
Various cases have been discovered in which

¹Ammonium persulphate is obtained in small colourless crystals having the composition $(\text{NH}_4)_2\text{S}_2\text{O}_8$. The substance readily absorbs moisture from the atmosphere and then becomes unstable. The salt should be stored in well-stoppered bottles. When a bottle of persulphate is opened a smell of ozone is often noticeable, this substance being formed together with the inactive sulphate when the salt is partially decomposed. Ammonium persulphate is very soluble in cold water (more than 30 per cent), but the solution is not very stable and it is advisable to prepare only a small amount of solution at a time (in the presence of 20 per cent of sodium sulphate these solutions may be kept for several days without alteration); persulphates are at once decomposed by boiling water.

Potassium persulphate is much less soluble (1.7 per cent at 60°F), but for this reason much easier to obtain pure. It may be used instead of ammonium persulphate as a reducer of photographic images.

reduction by persulphate is prevented or retarded by certain dyes adsorbed on the silver of the image during previous treatment (Lüppo-Cramer, 1928).

Persulphate converts silver into silver sulphate, which, in proportion as it is formed, tends to accelerate the attack on the remaining silver.



Ammon persulphate Silver Silver sulphate Ammon. sulphate

The presence of chlorides, which is practically inevitable, causes trouble (E. Stenger and H. Heller, 1910) if the amount of sodium chloride is as much as 0.01 per cent: this is noticed as an exaggerated superproportionality with a discontinuity in the reducer for a certain density; this value of density is raised by increasing the amount of chloride present (G. Higson; S. E. Sheppard, 1921). It will thus be understood that reduction by persulphate may be impossible with tap water which is relatively rich in chloride, such as may be found in some coastal districts.

Certain reducers which, in the absence of chlorides, hardly ever behave in a way other than subtractively can, when a suitable amount of chloride or bromide is added to them, dissolve the silver of the high densities, whilst that of the low densities is converted into chloride or bromide.

The presence of chloride in a persulphate reducer shows itself by the formation in the bath of a slight white precipitate round the dense parts of the negative.

The rate at which persulphate attacks the silver varies considerably with the acidity of the substance. The action is controlled by the addition of a trace of sulphuric acid or of a very small quantity of a silver salt (even of a small amount of an already-used solution) or of iron alum (Sheppard, 1918-1921); all these substances slightly diminish the risk of "poisoning" by chlorides.

The reducing bath is prepared when required for use as follows—

Ammonium persulphate	2 to 5 g
Sulphuric acid ¹	0.1 g
Water to make	100 ml

The reduction, which is comparatively slow at first, gradually gains in speed and may become too rapid. The action of the bath must be stopped a little before the desired effect has

¹ A solution of about 1 per cent of sulphuric acid may be made up and 10 ml used for 100 ml of the bath.

been attained; this is done by plunging the negative, without intermediate rinsing, in a solution of about 10 per cent of anhydrous sodium sulphite, which at the same time dissolves any traces of silver chloride formed in the film. The negative is then washed in several changes of water.

The microscopic observations of J. I. Pigg (1904) and of W. Scheffer (1906), on tests carried out on identical pieces of the same scale of tones before and after reduction with persulphate, showed that the persulphate acts simultaneously throughout the thickness of the film and attacks the large grains first.

561. Reduction of Granularity by means of Indirect Proportional Reduction. A. Scyewetz (1938) recommended the following method of proportional reduction giving the benefit of the fine grain of negatives developed in paraphenylenediamine.

The silver image is converted into silver thiocyanate by bleaching in a solution containing 10 per cent of potassium ferricyanide and 0.5 per cent potassium thiocyanate. After rinsing, the image is re-developed in a developer containing 6 per cent anhydrous sodium sulphite and 1 per cent paraphenylenediamine (free base). By this means the gamma is reduced (0.8 to 0.5 in one treatment) without undue reduction of threshold speed. The image produced on a high-speed emulsion without special precautions in development may thus yield an image with a granularity comparable with that of a fine-grain emulsion.

The fact that no silver can be detected in the developer solution afterwards suggests that the reduction in grain size so apparent in photomicrographs, is due to a change in the structure of the silver resulting in more compact grains than those originally present. It is not certain, however, whether this treatment results in a genuine reduction of graininess in the print, since the negative of lower gamma will have to be printed on harder paper.

562. Indirect Reduction of Heavier Densities. The image is treated in a bath containing about 2 per cent of potassium ferricyanide and 2 per cent of potassium bromide, in which it gradually bleaches. The operation is interrupted by washing in plenty of water a little before the higher densities have been completely bleached; the remaining silver is then dissolved in a solution of potassium permanganate acidified with *acetic acid* (R. Namias, 1911-1925).

After dissolving the residual silver, the nega-

tive is washed thoroughly and is transferred to a solution containing about 10 per cent of sodium bisulphite which decolorizes the gelatine and dissolves the acetate and bromide of silver formed; it is then re-developed in any ordinary M.Q. developer whilst exposed to weak light.

It is also possible to protect the greater part of the silver against the action of Farmer's reducer by transforming it into silver sulphide, or by toning it with gold or selenium. The silver can also be converted to bromide or chloride and re-developed superficially, the unreduced silver halide being dissolved in a fixing bath.

WORKING-UP

563. General Notes. By the term "working-up" is meant the various methods of correcting negatives by hand in such a way as to modify the relative printing values of certain areas of the image which have a simple outline. This may be done in order to remedy any irregularity arising from faulty working in making the negative; or it may be to improve the rendering, for example, by reducing the contrast, which is sometimes great, between sky and foreground in a landscape or between the lights and shadows of an interior photograph; or to obtain the details of the image of white clothing, or to subdue the too pronounced details of a background on a portrait negative or on the negative of a commercial subject.

In all the methods of working-up involving the application, with a brush, of an intensifier, a reducer, or a dye, it is an advantage to use liquids which are sufficiently dilute and to carry out the operation by successive applications of the same reagent. In this way the appearance of sharply-defined edges to the area treated may be avoided; such sharp edges, if they do occur, frequently do not coincide exactly with the outline which is intended to be followed. The edges of partial, successive treatments overlap one another to some extent, and give a graded effect which is much less obvious.

These operations are best carried out on a retouching desk, and if they have to be done as a matter of commercial routine the use of folding desks is to be avoided. These are by no means steady and do not give sufficient support to the forearm. The amateur may construct an illuminated table by placing a strong piece of glass on two boxes. The under side of the glass must be covered with white tracing paper and may be illuminated by means of light diffused from an inclined sheet of white

cardboard. The light may be supplied to the latter from a window or lamp which is screened by a blind from the view of the operator.

564. Local Intensification and Reduction with a Brush. In order to allow of control, it is necessary to choose methods which make use only of a single solution and which do not produce more than temporary coloration of the gelatine; thus the mercuric iodide intensifier and Farmer's reducer, or one of their variants, are suitable.

If the sodium or potassium cyanides (dangerous poisons) are obtainable, they may be used with advantage in a 4 per cent solution to replace the solution of sodium thiosulphate in this reducer. A stable mixture is thus obtained which does not leave the slight yellow coloration of ferricyanide; this is useful for dealing with paper prints which are to be locally reduced.

The operation is preferably carried out on the wet negative, which has been well wiped. The negative is mounted horizontally and illuminated from below (for reducing a sky, it may, however, be held almost vertically, with the image of the sky at the bottom). In order to help the liquid to adhere to the gelatine and to prevent its excessive diffusion on to neighbouring regions, its viscosity may be increased by dissolving sugar or by substituting glycerine or glycol for a part of the water in the mixture. In the case of reduction, the negative must be rinsed between each application.

565. Local Tinting of the Gelatine. Working up may be done by the additive method of tinting those parts of the negative which are too clear, or by the subtractive method of uniformly tinting the gelatine and then decolorizing it in those parts of the negative which are too deep. Which method is preferable depends on the relative areas of the parts to be tinted and to be left plain.

For *additive tinting* one chooses a water solution of a dye which is absorbed by the gelatine but is not fixed by it, and which may therefore be completely removed by washing in cases where it is desired to obtain the negative again in its original condition. Of the substances complying with these conditions are notably *new cocine*, giving a poppy-red colour (F. Schmidt, 1913), or *naphthalene black A* (G. L. Wakefield, 1938) and *tartrazine*, a lemon-yellow dye. When using cocine the work can be controlled better by placing a blue-green filter behind the negative as the visual density is then little different from the printing density

although actually a little higher (H. Cartwright, 1935). The first trial applications should be made very carefully, only experience being able to teach the effect of a given intensity of colouring, red or yellow.

At the start a comparatively concentrated stock solution of one or other of the dyes is prepared, and from this stock solution are made up two solutions for use; one of these is so dilute that a single application by means of a brush on a transparent part of the gelatine produces only a very weak coloration which can hardly be seen; the other is about five times more concentrated. The colour is applied with a sable brush No. 2 or No. 3 for very small surfaces, No. 4 to No. 8 for large surfaces, according to the size of the negatives.

The brush, soaked in the diluted solution and well wiped, is moved over the parts to be tinted without breaking contact between the brush and the gelatine until all the liquid has been absorbed. The brush is re-charged and wiped, and the process continued, returning as often as necessary to the same parts, and, if necessary, allowing the gelatine to dry when it becomes saturated with water. It is only by the superposition of a great number of very thin layers that perfect uniformity is obtained, and slight errors of outline are made negligible. The more concentrated solution is only used when a certain amount of skill has been acquired, and even then only to obtain very intense tints; in any case it is as well to prepare the film by at least one treatment with the diluted solution.

For *subtractive tinting* a uniform yellowish-brown coating is produced by bathing the negative for some time in a solution of potassium permanganate containing 1 g per litre, without any addition of acid. After the negative has been rinsed and dried, local decolorization is carried out by means of a dilute solution of sodium bisulphite (e.g. 5 parts of the commercial solution diluted to 100 parts), thickened with glycerine or gum arabic (R. Namias, 1914). When the work is finished, the negative must be washed in a strong stream of water or shaken vigorously in a large dish of water.

566. Local Abrasion of the Negative. In order to diminish the density of small areas of the image, the surface of the gelatine may be rubbed down by means of the finger or a piece of wash-leather with a little powdered pumice or powdered cuttle-fish bone; if a less vigorous

treatment is required, the rubbing may be done with a wad of flannel or a skin stump soaked with metal-polish, or merely moistened with alcohol.

Abrasive pencils are sometimes used. These are prepared as follows: melt some hard paraffin wax and thoroughly mix into it some very finely powdered pumice. The amount of the latter should be as great as possible, while allowing the mixture to be poured. Mould in paper cartridges which have been made by rolling paper round a pencil. After the wax has set, the pencils may be peeled for the whole or part of their length, and may be pointed for allowing work to be done on very small surfaces. When a negative has been worked up in this way any grease is removed from it with light petroleum spirit (Kate Smith, 1925).

567. Work on the Back of the Negative. A little carmine (moist water-colour) may be applied with the finger to the back of a glass negative, so as to cover uniformly those parts which are to be blocked out; the boundaries of these parts may be overstepped, and in such cases the excess may be removed with a moist duster, followed by a moistened brush. Printing must be carried out in diffused light, so that the thickness of the glass will prevent the outline of the work from showing too clearly in the print.

The back of a glass negative may also be covered with colourless or tinted *mat varnish*. Those parts which are to be clearly printed are then cut away with a scraper or with a wad moistened with alcohol, according to the area of the part to be treated. Parts which need darkening are covered with colour, as above, or are worked up with blacklead (graphite, plumbago), put on with a dry brush or with a soft stump.

An excellent mat varnish of average grain may be prepared according to the formula given below. The resins are dissolved in the ether¹ in a flask fitted with a sound wood cork. When they have dissolved, a process which may take several days in spite of frequent shaking, the

benzene is added slowly, and the mixture is allowed to stand at least a week before the clear liquid is decanted—

Ether . . .	700 ml
Sandarach . .	65 g
Mastic (tears)	15 g
Benzene to make	1000 ml

A finer grain is obtained by increasing considerably the amount of ether; on the other hand, a slight increase in the amount of benzene gives a much coarser grain. The mat varnish may be coloured yellow by dissolving a certain amount of *aurantia* in it.

The precautions necessary for spreading the mat varnish on the glass side of the negative are described later in the paragraph dealing with varnishing (§ 575). The chief thing to avoid is the application of any varnish to a place already dried. A negative on which the varnishing has not been successful may be cleaned by rubbing with a wad of cotton wool moistened with methylated spirit.

None of these methods is suitable for film negatives, but equivalent results may be obtained by working on a thin sheet of mat celluloid or on a piece of tracing paper which is fixed to the back of the film by pieces of cellulose tape.

568. Reduction of Contrasts by Soft Positive. It has often been suggested (A. Leitner, 1890) that excessive contrast in a negative may be compensated by placing against its back a soft positive transparency taken from the same negative. A special "auto-retouching" printing frame was indeed constructed (E. Artigue, 1903) for this purpose; with this apparatus a suitable transparency, which had been previously printed in the same frame, could be interposed in correct register.

This method is frequently used to reduce the contrast of subtractive colour transparencies (Kodachrome, Agfacolor, etc.), for the making of paper prints. The positive is then usually called a mask.

569. Blocking-out. The object of blocking-out is to obliterate all traces of background in a photograph which could not be taken against a white ground; the shadows cast by an object standing on a white ground are also obliterated by this method. The professional worker generally avoids these shadows by arranging the objects on transparent glass and photographing them from above. The glass is supported above a well-illuminated white background and far enough from it to prevent any shadows being

¹ Ether, sometimes wrongly called sulphuric ether, is a very volatile liquid the vapour of which is very heavy and inflammable. It must be stored in well-corked bottles. The handling of ether, or the preparation of a mixture containing ether, must not be carried on near a fireplace or flame. The mat surface of this varnish is due to the sandarach used being insoluble in benzene, and so being precipitated, during the evaporation of the ether, in minute grains enclosed in a transparent layer of mastic.

projected. For this, one of the following methods may be used. The negative may be worked-up by tinting the gelatine in the way previously described (§ 565), or an opaque paint may be applied, either to the glass side (for a portrait in which the outlines are not usually very clearly marked) or to the gelatine surface (photographs of furniture, machines, etc., in which the outlines are sharply defined). Water colour body-paint or water colours (chrome yellow, vermillion, india red, etc.), or a solution of 20 per cent bitumen in turpentine thickened with a little wax, or special opaque paints may be applied with a brush or pen (at least for the outlines) to a breadth of about half an inch. Areas beyond this band may be masked by covering them with opaque paper. Good water-colour brushes, giving fine points, must be used. Before starting work it is advisable to remove all traces of grease from the surface of the negative by rubbing lightly with a wad of linen or cotton soaked in methylated spirit. In order to dilute the colour to the desired strength and to make sure of rapid drying, alcohol, or a mixture of alcohol and water, may be used.

570. Spotting. Spotting is the process by which the clear spots on a negative (dust, air bubbles, scratches, etc.) are touched out. For this purpose very small sable brushes are used; these, when moist, must give a very fine point. It is usually impossible to match the density of the spot exactly with that of the image, and thus it is usual to try to produce a slightly greater density in the spot than exists in the surrounding image. The work is then finished by retouching the positive prints.

Spotting is carried out on a well-illuminated retouching desk. The ground glass of the desk should be masked with a sheet of black paper having an opening of small diameter. The different parts to be spotted are then brought one by one over this opening, so that attention is concentrated on the spot to be treated.

For this purpose black water-colour, more or less diluted, may be used, or indian ink thickened with gum arabic or strong liquid glue (usually obtained in tubes); or blacklead mixed in a little negative varnish (§ 576). Mistakes may then be cleaned off by means of alcohol, but negatives which have been retouched in this way cannot be varnished unless a varnish is chosen which has no action on the resins of that previously used.

The work is followed through a lens. It is essential not to allow the colour to go so far

as to form a ring round the hole to be filled, otherwise the defect is made worse. For very small holes, the colour used must be fairly thick; only a little must be placed on the brush, and the latter must be held perpendicularly to the surface of the negative.

RETOUCHING

571. The Purpose of Retouching. As a rule, the term "retouching" (negative retouching) is used to describe work done on the gelatine of a negative with a pencil and knife. Retouching corrects certain technical faults in negatives and, above all, faults of modelling. It is an almost universal rule in portrait photography to tone down or suppress wrinkles, freckles, and superfluous hair, to accentuate some lights and to lessen shadows which are too deep; often to modify an expression, and sometimes even to change the form of the face.

In professional practice retouching on the negative may be replaced by employing make-up on the model using a similar technique to that employed in film studios where retouching is impossible.

No retouching is admissible on negatives whose interest is scientific, historical, or documentary.

As a matter of principle, retouching should never be employed to make up for faults if the opportunity is available to avoid them by making a new negative under better conditions.

The beginner must be patient and should practise as much as possible on waste negatives. He will save a great deal of time if he can arrange to take some lessons from a practised retoucher.

The amateur who wishes, in an exceptional case, to retouch one of his own pictures, will save time by making an enlargement, on which all corrections may be much more easily effected, then making from this enlargement a negative of the size required.

572. Retouching Appliances. The retouching desk, large and firm, should be installed for preference near a north-light window, and at such a height that the retoucher may work seated before it without having to lean forward. Blinds must be arranged to screen both desk and worker from light at the sides and back. For work with artificial light it is often advantageous to cover the usual mirror with a sheet of white mat paper.

The folding desks described in many catalogues should, as far as possible, be avoided.

They may, however, be considerably improved by replacing the silvered mirror with which they are fitted by a mat opal glass, and the ground glass serving as a support for the negative by a piece of clear glass.

The knives should be of very good quality and very carefully sharpened; one may use a surgeon's lancet, a vaccinating pen mounted in a solid penholder, or a large tailor's needle of which the point has been hammered and ground so as to obtain an edge formed by two surfaces inclined at about 45°, the needle then being fixed in a wooden handle, or mounted in the handle of an engraver's needle. A small oil-stone (Arkansas stone, white and translucent) is used for sharpening the scrapers; the surface of this stone must be kept soaked with mineral oil. Sharpening is finished with a razor strop.

It has also been suggested (R. Demachy, 1905) that engraving tools and the triangular scrapers used by engravers should be used for removing details or undesirable reflections from negatives. For local abrasion of the film, the use of a scraping brush of metal or glass wire has been recommended.

We must also note the use of stippling tools, which are similar to pencil shells. In the inside of one of these tools is a point which is actuated by a minute electric motor, either with a to-and-fro motion or with an eccentric circular motion.

The pencils for negative retouching are of the best-quality graphite, selected from the groups F, H, HB, and B, or the bare leads of similar grades mounted in the corresponding lead holders, inside which the leads may be completely covered in order to protect them when not in use.

The letters constituting the distinctive marks of the various grades of pencil are the initials of the adjectives *firm*, *hard*, and *black*. The repetition of the letters H and B correspond to grades which are of increasing hardness or blackness. It must be remembered that the bare leads increase in diameter on passing from the hardest to the blackest, and therefore lead holders marked with the same letters should be used so as to avoid confusion.

For some time past use has been made of lead holders in the interior of which the lead is actuated by longitudinal to-and-fro movements or by eccentric circular motion.

Pencils should have long and very regular points; the wood is cut for a length of 1½ in. or 2 in., care being taken not to break the lead. A little square of emery paper is then folded in

two with the emery inside; this is held between the thumb and first finger of the left hand, and the lead of the pencil is introduced into the fold and turned between the fingers of the right hand, at the same time giving it a to-and-fro movement.

Pencils will not as a rule mark bare gelatine or the varnishes generally employed to protect negatives; the surfaces must first be prepared by means of a special varnish (retouching medium).

In order to allow of pencil work without varnishing, the negative may be treated with powdered pumice gently rubbed in by circular movements of the palm of the hand.

Retouching medium may be prepared by dissolving gum dammar in benzene, or, better, in a mixture of equal volumes of benzene and turpentine. The proportions are 0.5 to 1.0 g to 100 ml, and a few drops of oil of lavender or castor oil are added.

The outfit of the retoucher should also include a good lens, and in order to avoid the fatigue resulting from the unequal use of the eyes with ordinary lenses, we cannot too strongly recommend the use of binocular lenses making use of both eyes, these lenses are generally fixed to the head by means of a ribbon, or by side pieces as in the case of spectacles, thus leaving both hands free.

573. Technique of Retouching. Work with the knife should always precede that with the pencil and it must not be lost sight of that the retoucher should always restrict his work to what is absolutely necessary, being guided by a good print from the negative.

Since gelatine always retains a considerable amount of moisture which does not allow of the best conditions for working, it is advisable, before commencing retouching, to dry the negatives by placing them for some time in an oven or near a fire, taking care not to melt or soften the gelatine.

The knife is used by its point or its edge, according to the extent of the marks which have to be erased or the outlines to be modified; it must be handled very lightly in the same way that it would be used to remove an ink mark on paper; avoid any heavy cuts which would pierce the gelatine. It must always be remembered that the pencil must be used on the scraped parts in order to finish the work and to equalize the density on the scraped parts with those of the surrounding areas.

Before proceeding to retouch with the pencil

it will be necessary to cover the portions to be worked on with a very light coat of medium. For this purpose, a very small wad of cotton wrapped neatly in linen is used with a drop of the medium on it, or the end of the finger may be used. The excess may be removed by rubbing with the palm of the hand.

Local application of medium to an unvarnished negative sometimes leaves a slight halo. This



FIG. 34.7. STROKES USED IN PENCILLING A NEGATIVE

may be avoided by previously cleaning the negative with a wad soaked in a little turpentine.

For preference, the hardest pencil capable of giving the desired effect will be used; thus the B pencil will be kept for those parts of which the density is to be considerably increased. The pencil should be applied very lightly in dots of fine hatching, straight or curved, or in overlapping circles. Each mark should be so light as to be hardly visible by itself; the direction of the marks should follow the general lines of the subject. Fig. 34.7 shows on an enlarged scale some of the styles commonly adopted for retouching. The pencil should always be applied very lightly, the pressure being slightly greater in the middle of each mark than at the extremities. If it is required to darken certain parts of the image considerably, they must be worked

over several times, each time putting on the marks at 45° to their preceding direction. Any retouching work which is too heavy may be lessened by knifing; moreover, at any time work may be entirely removed with a little turpentine.

During the process of retouching, it is well to examine the negative from time to time by turning it gelatine side downwards on the desk in order to judge the effect better.

Parts which are not dark enough, due to insufficient pencil work, may also be treated by stippling them with a fine brush moistened with crimson lake (water-colour).

After the retouching has been finished a trial print is made and is carefully compared with the original print.

574. Added Backgrounds. Some photographers occasionally pose their models in front of a black background, filling in a background to the negative by subsequent work on the glass side. One of the methods used for this purpose is very old (La Blanchère, 1863), and has even been used by some celebrated painters to make "negative drawings" of pictures and so to furnish an infinite number of prints by means of photographic printing. The negative (or plain glass) is placed on a black ground (velvet, cloth, paper) and the desired design is drawn on the glass by painting with white body-colour; it thus appears as a positive by reflection and a negative by transmitted light.

For very simple backgrounds (draperies, clouds, etc.), a very light and uniform layer of finely-powdered red chalk may also be deposited on the glass; this is worked on by wiping off with a cloth or stump. In this way only very feeble contrasts can be obtained, but the effect may be very agreeable. The work is protected by spraying with a "fixative" or by covering with another sheet of glass.

CHAPTER XXXV

VARNISHING, STRIPPING, NUMBERING, CLASSIFICATION, AND STORAGE OF NEGATIVES

575. Varnishing of Negatives. The varnishing of negatives ensures them against numerous accidents. It is advisable for negatives which are required for large numbers of prints, and which in time may become scratched by rubbing. Varnishing is strongly recommended for negatives which have been retouched to any extent, but it is essential, in this case, to make sure, by trial on a waste negative, that the varnish to be used will not destroy the pencil retouching by dissolving the film of medium which serves as a substratum. Finally, when enlarging by direct light, varnishing of the negative lessens the effect of minor superficial scratches which are not noticeable in contact prints. Certain varnishes, called *hot negative varnishes*, can be used only if the negative has been previously warmed to a temperature of at least 90°F. Unless this is done, a mat surface is formed by condensation of the moisture in the atmosphere on the surface of the varnish, which is cooled by the evaporation of the solvents.

Warming of the negatives is dispensed with if *cold negative varnishes* are used, the only precaution necessary being thorough drying of the negative beforehand. Varnishing of negatives should never be carried out in a damp or cold room.

A number of satisfactory varnishes are sold commercially but, if preferred, any of the formulae in the following paragraphs are suitable.

576. Preparation of Varnishes. Varnishes prepared with alcohol are generally used for glass negatives, and, since they do not dissolve the dammar of the medium, can also be applied to retouched negatives. Ordinary collodion to which a very small quantity of castor oil has been added is occasionally used; and a solution of celluloid in amyl acetate is sometimes employed. Alcohol varnishes should never be applied to films (which seldom require varnishing), as the alcohol dissolves the camphor, which is one of the essential constituents of celluloid. Instead, a water varnish for retouched negatives, or a benzene varnish in the case of unretouched ones, should be used.

It should be borne in mind that the various solvents usually employed in the preparation

of varnishes are inflammable; if it is desired, therefore, to hasten solution of the resins by warming the mixture, the operation should not be carried out near a naked flame. Ether, or any mixture containing ether, should never be heated. All risk of fire can be avoided by the use of non-inflammable solvents, such as carbon tetrachloride and other chloro compounds, in the preparation of varnishes.

Hot Negative Varnish. The following varnish will take retouching quite easily, and is compounded in the cold or over a moderately warm water bath.

Sandarach	150 g
Essence of lavender or aspic	15 ml
Alcohol, 96 per cent, to make	1000 ml

Cold Negative Varnishes. Waste pieces of celluloid film can be used in the preparation of the following varnish, after they have been washed and dried—

Celluloid	15 to 20 g
Amyl acetate to make	1000 ml

For unretouched negatives, one of the following varnishes, which take work with a pencil easily, can be used—

Sandarach	100 g
Acetone	400 g
Crystallizable benzene	400 ml
Denatured alcohol to make	1000 ml

or—

Powdered copal resin	50 g
Gum dammar	20 g
Carbon tetrachloride to make	1000 ml

The latter must be prepared boiling and filtered while hot.

Water Varnish for Films. White gum lac (125 g) are dissolved in 250 ml of alcohol. When dissolved, 200 ml of concentrated ammonia are added. The gum lac is thus precipitated in a finely-divided state, and the whole should be shaken several times to re-dissolve it (to a soapy resinous state). Boiling water is added to bring it to a volume of 1,000 ml, and the whole is kept on a water bath for a while. The liquid is

never quite clear and should be used only after it has stood for some time.

Benzene Varnish for Films. A 2 per cent solution of gum dammar in crystallizable benzene is used. The film should be allowed to dry for several days, otherwise it might adhere to anything with which it is pressed in contact.

577. Application of the Varnish. Plates to be varnished should be thoroughly dried by keeping them for some time near a source of heat. A

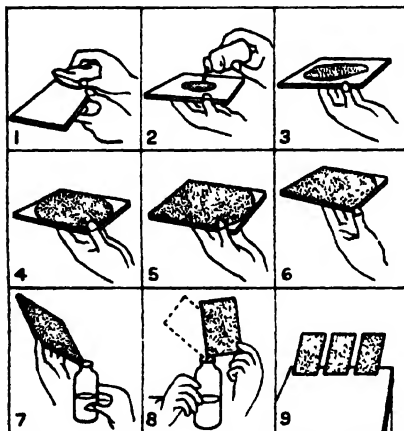


FIG. 351. MANIPULATION IN VARNISHING A NEGATIVE

drying cabinet in which hot air circulates is very useful.

For cold varnishing, the plates are first dried in this way and then left to cool. When cold carefully dust the plates just before the application of the varnish. The knack of coating the varnish can be acquired after several trials, but its description is somewhat lengthy. Fig. 351 shows the various stages of the operation. The plate is balanced on the fingers of the left hand and kept level under the thumb at the left-hand corner. The varnish is poured on to the centre of the plate until it covers about one-third of the surface. It is then allowed to spread until the liquid reaches the two sides; of the corner opposite the thumb. By careful manipulation, this corner is inclined, then the other corners in succession, care being taken that the varnish does not reach the thumb and run up the arm. When the whole of the plate is covered, it is raised first at an angle of about 45° and then vertically, allowing the excess of varnish to drain into the bottle. While draining, the plate should be rocked from side to side to prevent

streakiness. The negatives should then be put to dry, away from dust.

For hot varnishing, both the plates and the varnish are first warmed, and the coating carried out preferably over a hot slab or a stove, observing the same precautions as given for cold varnishing.

Films can be varnished by immersion in a dish which is filled with varnish to such a depth that the film is completely covered. After a few minutes, having ascertained that there are no air bubbles under the film, the latter is slowly lifted out, allowed to drain for a minute or two, and finally hung up by a corner until completely dry.

When using a water varnish, the films can, if required, be varnished as they come from the last wash water.

578. Removal of Varnish from Negatives. Glass negatives, which have been varnished, and which have been subsequently found to require after-treatment, can be cleaned by allowing them to soak for some time in denatured (industrial) alcohol in which 2 per cent of caustic soda or caustic potash has been dissolved. The varnish very soon becomes milky and can then be easily removed by gentle rubbing with a wad of cotton wool soaked in the alcoholic solution of soda. The negative is then washed in several changes of water and put to dry.

The varnish from a water-varnished film negative may be removed by immersing in a very weak solution of caustic soda (about 1 per cent) to which about 20 per cent of industrial alcohol may be added to avoid excessive swelling of the gelatine. The operation is completed by gentle rubbing with a tuft of cotton wool, and washing in several changes of water.

Gum-dammar varnish can be removed from a film negative by prolonged immersion in rectified benzene (crystallizable benzene would evaporate too quickly). The cleaning is completed by rubbing with a wad of cotton wool impregnated with crystallizable benzene, and the negative put to dry.

579. Oiling of Paper Negatives. Prints may be made from paper negatives without treating the latter specially, but exposure is considerably prolonged, since the paper absorbs an appreciable proportion of the incident light.

To shorten the exposure it is usual to make the paper translucent by impregnating it with a varnish or a fatty substance. It is essential in this case not merely that the paper be dry, but it should be dried by heat immediately before applying the treatment; otherwise the

water imprisoned in the fibres prevents the penetration of the substance into the pores in places, and considerably accentuates the grain of the paper, which is then more marked than if the paper had not been oiled. The paper should be dried before a fire or in a hot-air oven.

The most practical method of oiling consists in painting the back of the negative (placed on the bottom of an upturned dish to avoid any projections) with a brush dipped in liquid paraffin. Two applications should be made with an interval of one hour between, and the oiled paper left for about two hours, afterwards removing any surplus oil by pressing between blotters.

580. Stripping Glass Negatives. Stripping, that is to say, detaching the emulsion from the glass support, is used for certain methods of printing which require a reversed negative, or to save a negative which is cracked but not broken (§ 528) or, on occasions, to reduce the space occupied by a collection of glass negatives. The emulsion layer can either be preserved as such, or mounted on a fresh support.

To avoid the swelling of the gelatine when removed from its support, it must be well hardened. Preferably the plate should be kept at least one hour in a 3 per cent solution of chrome-alum or ordinary alum, quickly rinsed to avoid crystallization of the alum during drying, wiped down and dried. In the case of emergency formalin may be used (§ 519). Whatever method of stripping is employed, the gelatine film is first cut through to the glass with a scalpel, razor blade, or a very sharp pen-knife, either about a quarter of an inch from the edge of the plate, or as far as may be done without encroaching on the required subject.

Commercially, a 1 per cent solution of hydrofluoric acid, is generally used for the purpose, which frees the gelatine by dissolving the surface of the glass to a slight extent.

Concentrated hydrofluoric acid (solution of about 50 per cent) is very dangerous to handle, a drop falling on the hand causes a blister which takes a long time to heal, and inflammation which spreads up the arm. In dilute solution the acid is no longer dangerous. Whatever its concentration, it dissolves glass, stoneware, and all usual metals, and can therefore be sent, stored and used only in containers (bottles, funnels, and dishes) of gutta-percha, cérésine, moulded synthetic resins, or possibly in susceptible materials protected by a thick coating of varnish or paraffin wax. If stripping is

carried out only occasionally, the difficulties arising from the use of hydrofluoric acid can be avoided by employing less drastic methods.

It is possible, for instance, to use a mixture, prepared at the moment of using, of equal volumes of a 5 per cent solution of sodium fluoride, and of a 5 per cent solution of hydrochloric acid or 1 per cent solution of sulphuric acid (measured in volumes).

After a few minutes the emulsion layer becomes detached. To make sure, the margin beyond the cut is tried with the finger-tip. The whole layer may then be lifted off. For this purpose, a sheet of paper (preferably parchmentized, also called sulphurized paper, or, failing this, good quality white paper) larger than the negative, is previously put to soak in a dish of water. This sheet of paper is now placed on the negative, which is laid flat on the table, and, working from the centre outwards, the water is expelled by means of a squeegee or a soft, thick, rubber roller. A corner of the paper is then gently lifted until a corner of the negative is visible. If the emulsion has not come away with the paper, it should be lifted with a blunt point (such as a soft pencil) to make it adhere to the paper and, taking hold of both paper and emulsion with the fingers, it is pulled off with a gentle and even movement. The emulsion thus taken off with the paper can then be transferred to its final support.

The above method, although quite suitable for small and medium sizes, is difficult for the treatment of very large negatives owing to the fragile nature of the gelatine film. In such cases the emulsion should be strengthened, before making the marginal incision, by coating it with a 2 per cent solution of collodion to which a little glycerine is added, and then left to dry.

If the negative emulsion layer is to be kept as such for making prints which require a reversed negative, it should be coated with a syrupy solution of rubber before collodion varnishing, and left until the excess of solution has drained off and the greater part of the benzene evaporated. Prolonged immersion in the bath of fluoride solution is necessary for the liquid to penetrate completely between the film and the glass.

581. A slower but very certain method (Liesegang, 1892, perfected by H. Drouillard, 1903) consists in placing the negative to be stripped, after it has been cut round the edges, in the following bath for *at least* half an hour

(it can be left there all night). This bath can be used repeatedly—

Sodium carbonate, anhydrous	30 to 40 g
Formalin	50 ml
Glycerine	10 ml
Water to make	1000 ml

On removal from this solution, the surface of the negative is blotted off, and, without any rinsing, it is then left to dry completely, hastening the latter process, if necessary, by gentle warming. The drying rack should be placed in a clean dry dish, as the film sometimes comes off while drying. If the emulsion does not then peel off easily the dry negative is placed in a solution containing about 5 per cent of hydrochloric acid. This causes an effervescence, some of the carbon dioxide gas thus evolved being liberated between the emulsion and the glass. In this way the emulsion becomes detached, or at any rate its adhesion is so reduced as to allow of its being removed on to paper as described above.

Finally, attention should be called to the following rapid procedure, which is very suitable for negatives of small size and which can be used after washing but before drying them (A. Popovitsky, 1900). The negative is immersed for 10 to 15 minutes in a saturated solution of potassium carbonate (§ 426), in which about 5 per cent of caustic soda or potash has been dissolved. The negative is then dried between blotters, polished with a soft cloth, and a cut made round the part required. One of the corners is then lifted with a penknife and the film detached with a gentle pull.

582. Stripping of Film Negatives. It is sometimes necessary to strip the gelatine emulsion from film negatives, even although such negatives, being extremely thin, can be printed from either side satisfactorily, provided care is taken to avoid poor contact.

To remove the emulsion it has been proposed (Lumière, 1903) to swell the celluloid base by immersing it in one of its solvents, such as acetone, to which enough water has been added to prevent solution.

Also, the following process has been recommended (Eastman Kodak Co., 1922). The surface of the negative is coated with a 6 per cent solution of gelatine, flowed on at the lowest possible temperature. After drying, the film is placed in a strong solution of formalin (25 to 50 per cent of the commercial liquid) for about ten minutes, and then again dried. A cut is then made with a penknife, and the negative

placed in a 15 per cent solution of acetic acid, when, after a few minutes, the emulsion layer can be detached from the support.

583. Transfer of the Emulsion Layer to a New Support. When the emulsion layer is to be transferred to glass or celluloid, the latter should be previously coated with an adhesive, such as a weak solution of gum arabic, or with a solution of gelatine of about 10 per cent strength poured on while hot and allowed to set to a jelly. When the new support is to be celluloid, this gelatine should be dissolved in glacial acetic acid of about 10 per cent strength, after which about a quarter of its volume of alcohol is slowly added, so as to make the gelatine adhere to the celluloid. For the occasional stripping of a negative a fixed-out and well-washed film or plate can be used. The film can also be transferred to a piece of perfectly clean glass which has been polished with French chalk or coated with a solution of wax in ether; after drying the film on this temporary support, it is coated with a syrupy solution of rubber, allowed to dry, and finally given a coat of collodion or celluloid varnish.

Either before or after transferring to the final support, the film should be washed with water to get rid of the salts used in the stripping process; when the washing is done before transferring, a piece of plain glass, larger than the film, is placed on the bottom of the dish on which the film can be lifted out without risk of tearing it.

Care should be taken to put the right side of the film in contact with the support. The side will vary according as the film is placed on a temporary or a final support, or if it is to be used for making direct or reversed prints. If, when the film has been taken off on a piece of paper, the upper surface is not that which must come into contact with the support, it can be transferred to another piece of paper and then applied to the prepared surface of the final support, which has been evenly wetted (or coated with a solution of gum, if this adhesive is used). The excess of liquid is removed with a squeegee or a rubber roller.

584. Removal of the Gelatine Coating on the Back of Film. When the gelatine coating on the back of a film has been stained or scratched it can be removed fairly easily (J. I. Crabtree and F. E. Ross, 1926). To do this, the emulsion side of the film is applied to an adhesive surface, and perfect contact is ensured by passing a soft rubber roller or squeegee, care being taken that

there is no defect in contact at the edges of the film in a width of about $\frac{1}{4}$ in.

The waterproof adhesive surface can be of glass covered with rubber (coated at least 30 minutes previously with a thin layer obtained by evaporating a syrupy solution containing at least 5 per cent amyl acetate), or glass covered with a coating containing vinyl resins, or surgical rubber strapping. The back surface is then moistened with a mixture of equal volumes of water and acetone. When the work is finished the film is separated from the adhesive and cleaned with petrol.

585. Removal of Emulsions from Waste Glass and Celluloid Negatives. In cleaning off the emulsion from old negatives and for recovering the silver contained in the films, the simplest method consists in softening the gelatine by long immersion in water to which a small quantity of caustic soda has been added, and then dissolving it by placing in very hot water. The partly melted gelatine is then scraped off and the cleaning of the support completed by leaving it for a minute or two in a very weak solution of sodium hypochlorite followed by rinsing in cold water.

Commercially, various enzymes are used to remove the gelatine by digestion. Celluloid films which have been freed from gelatine with caustic soda and insufficiently washed have been known to ignite spontaneously while drying.

Another method is to soak the gelatine in a solution of sodium carbonate of about 10 per cent strength to which a little caustic soda has been added; when dry, the film is stripped off by treating with hydrochloric acid, it being of course unnecessary to take any of the precautions given above for proper stripping.

586. Titles, etc., on Negatives. Numbers, titles, and signatures may be added by cutting out the letters from a dense part of the image with a fine-pointed graver, or by writing with a pen on a lighter part. The latter method is preferable, being quicker, and the work is of better quality. Instead of writing in ink, which requires the use of a retouching desk, it is simpler to use yellow water-colour which has been thinned to a suitable consistency. The writing is then quite visible by reflection, and can be done with the negative flat on an ordinary table. It may be useful to write from left to right, as is the practice of engravers and lithographic draughtsmen, on the negative, turned upside down, making the characters as shown in the accompanying specimen (Fig. 35.2). After a few hours'

practice it is possible to write in this fashion quite readily and without using a specimen.

For engraving negatives there have been placed on the market bronze styles fitted in an insulated handle and heated to about 176°F, and connected to alternating current by a small electric bell transformer. The hot point melts the gelatine, leaving a transparent line with sharp edges. Another more complicated method for transferring an inscription on paper to gelatine has been suggested. The inscription is written

0153420180
 d1e2fnnmxh5
 apcqe7dμ!7k1wuo6
 uob0b21n1mx15
 vbcdeefchi7k7w
 0153420180
 b1e2fnnmxh5
 spcqe7dμ!7k1wuo6
 uob0b21n1mx15
 vbcdeefchi7k7w

FIG. 35.2. REVERSED TYPES FOR TITLING NEGATIVES

on glazed paper, using a glass pen, with a very concentrated solution of potassium ferricyanide thickened with a little glycerine and to which a small quantity of blue dye may be added. The paper is transferred to the gelatine surface which has been previously moistened in the required place. When it has been in contact with the gelatine for a few minutes, i.e. when the silver has been attacked, the silver ferrocyanide so formed is dissolved out in a fixing bath. The negative should then be washed.

In the case of negatives made for large numbers of prints, the title is generally set up in type, and printed on to the negative. Special rubber type is sold giving an imprint similar to that shown in the specimen. When the letters have been assembled in the type holder, they are printed on a thin part of the negative with a greasy ink. The density of the imprint is increased by dusting over with a little blacklead, afterwards brushing off the excess: the lead

adheres to the greasy ink and not to the dry gelatine.

Another method is as follows. Using a good typewriter, from which the ribbon has been temporarily removed, the title is written on a piece of very thin paper which has been placed between the prepared surfaces of two pieces of unused black carbon paper. In this way the letters are printed on both sides of the paper at the same time, thus obtaining sufficient density. This is then attached to the negative and the two printed together. A clear area for the title may be formed on the negative as follows. A black gummed strip is stuck on the emulsion before exposure, on the side corresponding to the bottom of the picture. This is detached before processing so as to allow free access for the fixing solution (E. J. Kloes, 1925).

Titles to print white on a blackground can also be set up in type and transferred to the negative in various ways. The impression can be made on thin sheets of Cellophane with a very stiff ink and moderate pressure, dusting over with blacklead as above while the ink is still tacky. The titles are then cut out, and the printed side fixed to the gelatine with a very weak solution of gum arabic which has been applied on the part to be covered.

The imprint can also be made on lithographic transfer paper with a good transfer ink. The titles, when cut out, are placed face upwards on a pad of damp blotting paper, and covered with some dry blotting paper to prevent their curling up.

After a few minutes the soluble layer of the transfer paper becomes sufficiently moistened, and the printed surface of each strip can then be applied to the gelatine of the negative in the required position, causing it to adhere by pressure with the fingers. The back of the paper is dried with two applications of dry blotting paper, and the transfer done by pressure with a burnisher. After some time (judging the correct length of time is the beginner's only difficulty; it is therefore advisable to take at least two proofs of each specimen, so that one can be used to experiment with on a waste negative), the back of the paper is moistened with a paint-brush, a corner raised with the point of a penknife, and the paper lifted smoothly off. When the gelatine is dry, the ink impression is strengthened by powdering with blacklead.

Titles which have frequently to be repeated, such as a trade-mark or a signature, can be copied on a contrasty plate or film from the

original. The prints can be made on transfer paper or on a very contrasty plate from which the emulsion is stripped, and applied while wet to the gelatine of the negative.

For titles to print black on a light part of the picture, a film negative of the desired text can be transferred to the negative after having scraped off the gelatine from an area to receive it, the title negative being secured with a weak solution of gum-arabic. The text can be made, for instance, with the help of a stencil of the type used by industrial artists or for titling amateur ciné film, and which permits of normal or reversed writing at will.

In the case of a signature which has to appear in black on a white ground, a method of double printing is generally used. A negative of the signature is made on a contrasty film or plate, any small defects being carefully blocked out on the dense portion, and the sides extended with masks of opaque paper. After exposing the sensitive paper under the negative of the subject, it is then exposed under that of the signature, adjusting the latter to a suitably chosen position, or setting it against stops of thin cardboard cemented to the signature negative.

587. Classification of Negatives. A methodical classification is necessary in order that negatives required for any purpose can be found without loss of time. To this end, all negatives should be numbered and arranged in numerical order. Since negatives of different sizes cannot be kept together without risk of accident, it is advisable, in order to avoid mistakes, to adopt a separate series of numbers for each size. Each size then forms a series designated by a letter which precedes the number.

An index of the negatives will naturally be carried out differently by a professional, amateur or research worker, classification being according to commercial importance in the first case, whilst technical information is of primary importance in the last two cases.

Such a file-index, besides containing numerical classification data (negative number, date, type of subject), and particulars of accounts (details of the order, agreed price, amount of deposit, promised date of delivery, amount payable) may also contain any information which is likely to explain the cause of a failure or deterioration, and any facts which will enable one to profit in the future by the experience gained (camera used, number of plate-holder, lens aperture, plate used, light-filter, lighting, exposure, and any further details). The register

may also contain any data which might facilitate the future use of the negative (suitable methods of printing, the best conditions for printing or enlarging, the most desirable method of mounting proofs, etc.).

In some cases the index can be usefully supplemented by a complete collection of actual prints contained in an album or card-index file. All or some of the particulars mentioned above (with, of course, the exception of accounts) may then be written at the side or on the back of the print instead of in the register.

588. Storage of Negatives. The most economical method of storing glass negatives, and that which requires the least space, is to keep them in the cardboard boxes in which they were originally packed. Each negative should be protected by a wrapper of some kind, on which the series letter and the number of the negative is written, to avoid the negative being scratched, or the retouching, working-up, or title on the negative being rubbed off. These wrappers should be, if possible, fairly transparent so as to allow the negative to be identified without removing it from its wrapper. In the case of glass negatives kept in a box it is quite satisfactory just to use interleaving sheets of paper giving the necessary information, instead of a complete wrapper for each plate.

The transparent envelopes usually sold for negative storage are quite suitable for films, but totally unsuitable for plates. The sharp edges of the glass cut the envelope when the plate is slipped in, and after a certain amount of handling, the edges of the envelope which overlap the plate become creased and bent. Again, the film side of the negative should never be allowed to come into contact with the gummed part of such envelopes, since gum of bad quality has been known to cause deterioration of the image.

The boxes should be kept on shelves in the same way that volumes are placed in a bookcase, and labels indicating the lowest and highest numbers of the negatives contained therein should be stuck on the side of the box or lid, exposed to view. Apart from the fact that this arrangement of the boxes on edge allows of their being taken out and replaced without disturbing the others, the boxes of negatives suffer the least possible strain, and are therefore less exposed to accidents. Owing to the considerable weight of a fair-sized collection of glass negatives, the shelves should not be fixed with brackets nailed to the walls or partitions, but

should be supported either by iron brackets securely screwed to the wall, or by wooden supports fixed to the wall and resting on the floor, placed close enough together to prevent any appreciable sagging of the shelves.

Similar arrangements could be adopted for storing a small quantity of film negatives, each film being protected by a transparent envelope or in an album containing envelopes of transparent paper for this purpose. For large collections, the negatives may be kept vertically as in a card index, in suitable boxes or drawers. Negatives should be stored in a room which is neither very damp nor very dry.

589. In Great Britain the storage of celluloid in the form of sensitive film or celluloid negatives is subject to the regulations set forth in "Statutory Rules and Orders, 1921, No. 1825" (H.M. Stationery Office, London, Edinburgh, Manchester, Cardiff, and Belfast, price 1d.), under Section 79 of the Factory and Workshop Act.

As regards sensitive films, kept on premises in a quantity which as a rule does not exceed 14 lb., storage in a drawer or cupboard in a private office or other room in which no handling of celluloid is done, is officially regarded as complying with the requirement for "safe storage."

The regulations in respect to developed negatives will depend to some extent on the amount of such negatives. Where the latter are of considerable weight, they require to be kept in a fire-resisting store, such as a cabinet or cupboard constructed of fireproof material, e.g. sheet metal, asbestos sheeting, or wood effectively treated to resist flame. This store requires to be of sound construction and is to be kept locked. The door or lid needs to be so arranged that there is no naked light or open fire near at hand. The store should not be situated in a workroom where celluloid is handled, nor on a staircase, nor near a door, nor in a passage through which persons might have to pass to escape in the event of a fire. The nature of the contents should be clearly marked on the outside of the store, and a cautionary notice put up prohibiting the use of naked lights. An adequate supply of buckets of water should be kept always available close outside the store, water being the best extinguisher of burning celluloid.

The foregoing recommendations are for general guidance, and are subject to modification, according to the quantity of celluloid, or on account of the design of the building or nature of the processes, at the discretion of the District Inspector of Factories.

PART 4

PRINTING PROCESSES

CHAPTER XXXVI

PRINCIPAL METHODS OF PRINTING

590. A great number of photo-chemical reactions are known on which processes for producing photographic positives can be based. There are also various reactions by means of which the substance forming the image produced by the action of light can be modified, thereby altering its colour (*toning*). The study of these processes has been limited to those in current use and a few others of particular interest.

Any classification of printing methods is largely arbitrary, and that adopted here is based on the nature of the photochemical reaction.

591. **Methods using Silver Salts.** Methods of printing with *silver salts* may be conveniently divided into two principal groups depending on whether the image is entirely formed by the action of light (these are known as *print-out* processes, also called *P.O.P.*), or whether it is obtained by the development of a latent image by a process very similar to that used for the production of negatives.

In the first case a silver halide (usually the chloride) is used in conjunction with either a soluble silver salt or some other substance capable of absorbing the halogen liberated by the action of light (a developer, for example, or some other reducing agent). The sensitive compounds may be formed either in the support itself, or in a "sizing" with which it has been previously coated (*albumenized* or *salted papers*), or an emulsion of the sensitive material may be prepared with gelatine or collodion and afterwards coated on the required support (gelatine *P.O.P.*; collodion *P.O.P.*). Certain papers belonging to this latter category contain the necessary toning materials (gold salts, or, more usually, selenium or tellurium compounds), incorporated in the actual emulsions, and are then known as *self-toning papers*. A considerable quantity of light is required to form an image on these various sensitized papers (exposures of about a quarter of an hour in good diffused daylight are required when contact-printing from a negative of average density) and the various manipulations can be carried out

in weak daylight. Thus it is not practicable to use such papers for projection printing (enlarging or reducing). The final tones of prints obtained in this way usually vary from reddish-brown to purplish-brown.

Printing-out papers can also be used by physically developing a very weak image, obtained by considerably less exposure than that necessary to produce a normal print.

In the second case (development papers), the emulsions do not differ essentially from negative emulsions except in being very much slower. For a long time manufacturers have made such sensitive papers in the form of gelatine emulsions, although several attempts have been made to use collodion for the purpose. The sensitive substance may be either silver bromide, silver chloride, or a mixture of the two. In all cases, such emulsions are too fast to allow of their being used for daylight printing. Gelatine-chloride emulsions are considerably slower than gelatine-bromide ones, and are insensitive enough to allow of their being handled in weak artificial light without the use of a safelight. This fact has led to their being incorrectly called *gaslight papers* (to be handled in gaslight). Silver bromide or silver chloride papers normally give black tones, whilst chlorobromide emulsions, which are of intermediate sensitivity, are used as a rule for the direct production of warm tones. These various emulsions, and particularly the more rapid ones, constitute the best material for enlarging purposes.

Toning of the silver image can be done either by replacing it by other metals (gold, platinum, etc.) or by converting the silver into a coloured compound (brown silver sulphide), or into a colourless substance by which a certain quantity of a coloured compound can be absorbed. The last-named process allows of a very wide range of colours being obtained.

592. **Methods using Iron Salts.** Ferric salts of several organic acids (oxalate, tartrate, citrate, etc.), and particularly their ammoniacal

complex compounds, are converted into ferrous salts by the action of bright light. This property may be used in various ways owing to the different properties of these two types of salts.

For example, ferrous salts give a blue precipitate with potassium ferricyanide, whilst no precipitate is formed with ferric salts, and it is possible to obtain a blue image which can be fixed by simply washing in water. *Ferro-prussiate* papers, based on this reaction, are used industrially in large quantities for making copies of tracings, the "blue-prints" thus obtained consisting of white lines on a blue ground.

Ferrous compounds are capable of reducing the salts of the precious metals to the metallic state, and this property forms the basis of the *kallitype process* and the *platinum process*. Such processes give grey or black tones by simple washing in water or by treatment with a solvent capable of dissolving the ferrous salt formed and also the silver or platinum salts.

593. Methods using Pigments and Bichromated Colloids. Various animal and vegetable colloids (gelatine, albumen, gum, etc.), when impregnated with a *bichromate*, dried, and exposed to light, are tanned by the chromium oxide which is formed during the photo-chemical decomposition of the bichromate. Differences of solubility and permeability between the parts exposed to light and those protected from its action may be used to obtain photographs in a large number of ways which have the following characteristic in common. In all cases the image consists of a pigment (colouring matter in powder-form, or ground with oil) or other colouring matter which has taken no part in the reaction.

For example, suppose a finely powdered pigment is incorporated in gelatine, and the mixture coated on paper; after sensitizing with bichromate it is exposed to light under a negative (neglecting for the time being the *transfers* usually necessary). It is then treated with warm water, which dissolves the unhardened gelatine, gradually revealing the picture, which now consists of pigment incorporated in insoluble gelatine. Whatever the chosen pigment, such papers are known as *carbon tissues*, since lamp-black was the pigment with which they were first made.

A film of bichromated gelatine, which has been washed with water after exposure to light under a negative, is not wetted in those parts which have been protected from light-action. Now *greasy inks* are repelled by a wet surface, and

can adhere only to a dry one, so that inking with a brush or roller will thus form an image consisting of printing ink, which can either be kept as such, or transferred to plain paper (*oil prints*, transfer prints in greasy ink).

A layer of bichromated gelatine which has been exposed to light under a positive is capable of absorbing dye from a dye-bath in the parts which have been protected from the action of light, as the dye is not able to penetrate those parts which have been rendered impermeable. In this way it is possible to obtain a perfectly transparent picture consisting entirely of stained gelatine (*hyarotype*).

Another process is as follows. Glass is coated with a thin layer of a mixture of gum-arabic, some hygroscopic substance (honey, glucose, sugar), and a bichromate, and the whole dried by gentle heat. This is then exposed under a positive, and a finely-powdered pigment spread with a brush over the surface. The moisture of the atmosphere, which is absorbed more rapidly on the parts protected from light than on those which were exposed, renders the gum-arabic adhesive again and capable of fixing the powder which has been dusted on, thus forming a positive picture when the excess of powder has been dusted off. This can be permanently fixed by varnishing if an inert powder has been used (e.g. plumbago), or by baking if the colour is vitrifiable (*powder or dusting-on process*; *photographic enamels*, and *photo-ceramics*).

594. Photo-chemical Formation or Destruction of Coloured Materials. There are a large number of photo-chemical reactions which can generate a coloured substance, destroy a coloured substance present, or destroy one of two reactants which react mutually to give a coloured substance. An example of this type of printing is the *diazotype* (of which there are various kinds all based on the photo-chemical destruction of diazo-compounds) which has gained considerable industrial importance and is largely replacing the iron-salt processes for copying drawings.

595. Conversion of a Silver into a Pigment Image. By making the silver of an image take part in a reaction giving rise to tanning products, it is possible to render insoluble the gelatine in the immediate neighbourhood of the original silver image. It is thus possible, starting from a silver image, to obtain pigment images by methods similar to those mentioned in § 594. In this way a developed print on gelatine-bromide paper may be either converted into an image in greasy ink (*oil or Bromoil process*),

which can be further transferred to plain paper, or it can be used to insolubilize the gelatine of a carbon tissue previously soaked in reagents which react with silver (*carbro* process).

On the other hand, having formed a silver image in a gelatine film containing a non-diffusing colouring substance, a reaction can be made to take place which destroys at each point a quantity of the colouring substance proportional to the amount of silver present. Alternatively the coloration not in the immediate neighbourhood of the silver can be destroyed. These methods are applicable to the production of coloured motion-picture films.

596. Supports for the Photographic Image. Photographs can be made on, or afterwards transferred to, a large variety of materials: papers of various textures, tints and substances, fabrics (silk, canvas), metals or metallized papers, glass, celluloid, etc. Of all these, the most commonly used support is paper, and the words "photograph," or "photographic print" are always understood to mean a paper print. Glass and celluloid (and its non-inflammable substitutes) are chiefly employed for *diapositives* or *transparencies* for ordinary and motion-picture projection.

Emulsion, ready coated on appropriate supports, and emulsion in a powder form, to be redissolved in water for coating, are made for a number of industrial applications.

An emulsion containing salts of silver has been sprayed on to the inside walls of a room, first covered with plastic paint, for the purpose of their decoration by producing enlargements on the walls (E. Mollo and H. C. Merrett, 1934).

597. Colour of Image and of Base. There is an almost unlimited choice of colours of the image and the tint of the base of photographic papers. Although a slightly-tinted base sometimes helps to suggest certain effects (§ 23), and variations in the colour and tone of the pictures themselves are useful in relieving the monotony of a collection, such means should only be used with discretion and in moderation. Engravings (lithographs, etchings, etc.) and original drawings, for the execution or printing of which the artist has a large selection of crayons or inks of the most varied colours at his disposal, are often finished in a black or warm black tone on white or slightly-tinted papers rather than in bright colours (excepting, of course, originals in colour). Still more should startling effects be avoided, such as would be given by the use of green for a portrait, or deep-red for a seascape or landscape. Finally, the colour of the picture and the tint of the base should be in perfect harmony. Thus, a blue-black image would not suit a cream or chamois base, whereas a warm black picture would go well with a base of that colour.

CHAPTER XXXVII

SENSITOMETRIC CONSIDERATIONS OF PRINTING

598. Although the considerations involved in this chapter apply to all printing processes, examples have been chosen, except where otherwise indicated, using silver salts which are chemically developed.

599. **Brightness Range of an Image on an Opaque Support.** For a given image the range of reflection densities (§ 15) is always much less than the range of transmission densities. The former is, in fact, insufficient for the correct rendering of a subject covering a wide range of brightness. The examination of a silver print on paper by transmitted light, using a very strong source for viewing, often reveals details in the shadows which cannot be observed by reflection.

Fig. 37.1 (F. F. Renwick, 1913) shows the relation between the densities of the same silver deposit on a transparent support when measured by transmission of diffused light (D_t), or by reflection (D_r) after placing the face of the image in contact with a sheet of glossy white paper. It will be seen that for equal amounts of silver D_r rises much more quickly than D_t and reaches a maximum of 1.4 when $D_t = 1.2$.

The image on the opaque support is seen principally by light which passes through the layer containing the image, undergoes a diffuse reflection from the support, and passes once more through the layer. In addition to this, there is the more or less uniform light reflected from the surface of the coating, due to scatter at the interface of the gelatine and silver grains. This gives a weak negative image and is comparable to the positive which can sometimes be seen when a negative is viewed by reflected light under certain conditions. Finally in mat or semi-mat papers, light is scattered by the matting agent (e.g. starch), which is incorporated in the emulsion, the grains of which are almost as numerous as those of silver in the high densities.

On glossy papers the maximum reflection density is found when the transmission density attains or exceeds 1.2. The figure for glazed glossy paper is slightly higher, whilst for a mat paper it is slightly lower. Thus it is unnecessary for a coating to contain more silver than is necessary to give $D_t = 1.2$ (M. Hesse and C. A. Mannheim, 1932), but in order to obtain a

satisfactory image, it is necessary to prolong the development until all available silver halide is reduced in the regions of maximum exposure, that is, until gamma has reached its limit. The maximum reflection density then rarely exceeds 2.0.

600. **Relationship between the Negative and Positive Sensitive Materials.** By varying the development time of a positive transparency material, it is possible to obtain any value of

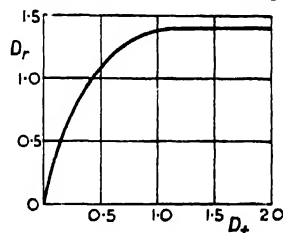


Fig. 37.1 THE RELATION BETWEEN THE TWO DENSITIES OF THE SAME IMAGE BY REFLECTED LIGHT AND BY TRANSMITTED LIGHT

gamma for the positive image up to the maximum ($\gamma_{P\infty}$). Using this property in conjunction with a suitable choice of exposure, it is possible to obtain positives with the same density range from negatives with widely differing density ranges.

Consider (Fig. 37.2, I) two negatives of different subjects, developed to different values of gamma (γ_N), the useful region of the characteristic curve being AB for one and CD for the other. In (II) are drawn the characteristic curves of the positive emulsions, these being arranged in different directions to those normally used in order to make the density scale of the negatives (D_N) coincide with the exposure scale of the printing material ($\log E_P$).

As the amount of light received by a print on the positive material is the product of the transparency at the corresponding point on the negative and the light falling on the negative during printing, the sum of D_N and $\log E_P$ is a constant. A variation in the light has the effect of moving the positive characteristic curve (and its $\log E_P$ scale) parallel to the D_N scale. For a suitable choice of working conditions, the characteristic curves of the prints, limited to their

useful range, can be $A'B'$ and $C'D'$, where A' and C' represent the same density (indicated by $a''c''$) on the D_p scale, and $B'D'$ also represent another density indicated by $b'd''$ on the same scale.

Unfortunately, the situation when making prints on paper is not so satisfactory. The paper is always developed to gamma infinity, since the image colour is usually unsatisfactory if development is curtailed. Hence the paper

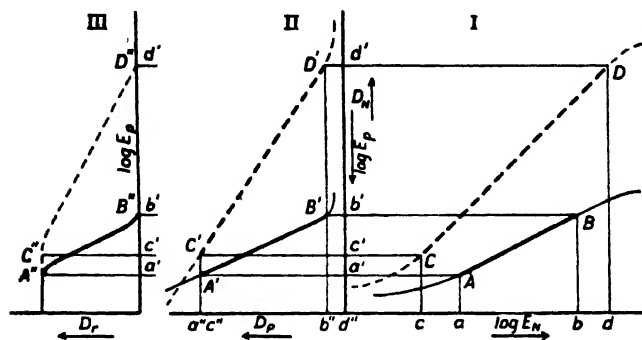


FIG. 37.2. THE RELATION BETWEEN THE CONTRAST OF A PRINTING PAPER AND THE DENSITY RANGE OF A NEGATIVE

can really satisfactorily match one negative contrast, or at best a fairly narrow range of such contrasts. This difficulty is solved only by the manufacturers providing a range of papers with different values of gamma infinity.

This variation in contrast grades available, of extreme importance for the success of prints, can best be seen by printing the same neutral density wedge on to several samples of paper of the same make but of different grades. When each sample has been developed properly, it will be seen that the print passes from black to white in a distance very different from one sample to another, corresponding to density ranges on the wedge of from 0.3 to 2.0. The exposures which give respectively the darkest grey which can be distinguished from black, and the lightest grey which can be distinguished from white, are thus in a ratio having 2 : 1 and 100 : 1 as its extreme values. This ratio is sometimes called the total gradation of the paper, but it is better to avoid this expression owing to the wide range of meaning of the word "gradation." Usually the density range to be printed falls between 0.6 and 1.6, the difference between the extremes then being 4 : 1 and 40 : 1.

The printing of the negatives considered

(Fig. 37.2, I) is thus only possible on papers with very different characteristics. The characteristic curves after development to $\gamma_{P\infty}$ are represented by $A'B''$ and $C'D''$ (Fig. 37.2, III) the exposure range being $a'b'$ for one and $c'd'$ for the other. In each case the exposure range is equal to the density range of the negative being printed.

601. In printing the negative AB on to the paper which has previously given the curve $C'D''$, it is not possible to obtain maximum black and clear white at the same time. Depending upon the amount of light used, it is possible, for example, to have a scale ranging from middle grey to black, which would be suitable for the representation of a very dark subject, or a scale ranging from white to middle grey, suitable for cloud effects, or a portrait of a girl dressed in white (high key).

If on the other hand, the negative CD is printed on to the paper which gave the curve $A'B''$, the whole scale of greys of the paper is used from black to white, but all the light tones will be indistinguishable from the white, or all the dark tones from the black. Alternatively, some of the light tones will be lost in the whites at the same time as some of the dark ones in the black. In the last two cases, examination of the print by transmitted light will reveal the shadow detail which could not be seen by reflection.

602. **The Contrast of Positive Papers.** Each type of positive paper is usually supplied by the manufacturer in several different grades, differing in their exposure range. When the exposure range is very long, the paper is called "extra-soft," and when very short, "extra-hard" or "extra-contrasty." These differences may sometimes prove troublesome, on account of lack of uniformity between manufacturers in indicating this important characteristic of their grades. For instance, one maker may describe a paper as "normal" which another manufacturer would term "contrasty," and another "soft." In recent years, agreement has been reached between the more important manufacturers in the United Kingdom with the result that the designation of paper grades is much more uniform.

Many photographic workers measure the extreme densities of their negatives in order to select a suitable grade of printing paper, and it is very desirable that the contrast of papers should be expressed numerically. A more definite indication of the shape of the characteristic curve than the present grading would be to quote its maximum contrast (gamma infinity).

The result of important statistical experiments, comparable to that undertaken by L. A. Jones in defining a speed criterion for negative materials (§ 258), have been published almost simultaneously by W. Romer and W. Royski, by L. V. Chilton, and by L. A. Jones and C. N. Nelson. The unanimous conclusion of these authors is that a grade of paper should be characterized by its *useful* scale, which is narrower than the total exposure scale. In order to obtain a perfect print, a negative of known density range must be printed on a grade of paper which has a *useful* scale equal to the logarithm of this range. The authors differ in the limit which they assign to the *useful* scale. Romer and Royski suggest as limits the points on the characteristic curve where the slope is 0.2 γ and 0.58 γ , where γ is the maximum slope of the curve; Chilton proposes 0.1 and 0.5. Finally Jones and Nelson recommend a lower limit chosen so that the slope at that point is 1/10 the slope of the tangent drawn from this point to the upper part of the curve.

603. Expressions for the Speed of Positive Sensitized Materials. So far the speed of printing papers has not been quoted by the makers, but this question is being made the subject of discussions by several national organizations for standardization. All the reports presented to these organizations propose that the speed criterion to be adopted should be based on the exposure E corresponding to the upper limit of the useful scale; the differences of opinion are only on this limit (§ 602), on the colour temperature of the lamp, and on the exposure time to be adopted for the test.

In the American system, based on the experiments of Jones and Nelson mentioned above, the speed of a paper would be expressed as 10,000/ E , the speed indices for all papers actually falling between 1 and 60,000.

604. Tone Reproduction from the Subject to the Print. A very ingenious graphical method (L. A. Jones, 1920) allows the predetermination of how the brightnesses of the positive image (a transparency or a print on paper) will reproduce the brightnesses of the subject (to an

approximation, since it depends on the lighting of the picture during examination), when the characteristic curves of the negative and positive materials are known.

In Fig. 37.3, has been traced (in quadrant II) the characteristic curve A' of a negative emulsion, the useful part being shown by the distance $\Delta \log E_N$. It is worth noting here that, due to light scattered by the lens and in the camera, the characteristic curve of the negative emulsion does not represent the negative obtained; each of the ordinates should be $\log \frac{1 + \Delta}{I}$,

when I represents the illumination at a point in the image in the absence of scattered light, and Δ is the additional illumination due to diffusion.

In quadrant III is drawn the characteristic curve A'' of the positive emulsion on which it is proposed to make the print (a paper, in the example chosen), this curve being placed in such a way, relative to the negative curve, that the extremes of black and white, of which the paper is capable, are utilized.

From a point a' chosen on the curve A' , a horizontal line is drawn cutting the curve A'' in the point a'' ; from this new point a vertical line is drawn which intersects at a''' the line drawn at 315° (− 45°) in quadrant IV. The intersection of the vertical drawn through a' and the horizontal through a''' is one of the points on the curve A , which indicates on logarithmic scales the relationship between the brightness, B_s , of the subject and the brightness, B_p , of the positive image. The whole curve may thus be constructed point by point. The line at 45° in quadrant I, or all lines parallel to it, represent ideal objective reproduction.

Two other negative and positive curves have been drawn, and also their corresponding true reproduction curves (to avoid confusion in the diagram, one has been drawn using the broken line in quadrant IV).

Of the various combinations thus tested, the best result (curves in broken lines) is obtained by the use of two sensitive materials (negative and positive transparency) in which the characteristic curves have a long straight portion.

605. Goldberg's Condition. The slope at a particular point on the reproduction curve is the product of the slopes g_N and g_P at the corresponding points on the characteristic curves of the negative and positive; for the reproduction curve to be a line at 45° (slope = 1), the product $g_N \times g_P$ should always be unity. This

condition is difficult to satisfy outside the linear portions of the characteristic curves, where it becomes $\gamma_N \times \gamma_P = 1$, which is the condition put forward by E. Goldberg in 1922. This condition, however, cannot be satisfied exactly in the photography of coloured objects as the gamma of the sensitive material varies with wavelength within the range of spectral sensitivity. A practical step which is often an

the paper of the optimum contrast and the optimum printing time can be avoided by measuring two suitably chosen densities on an appropriate densitometer. The densities are not necessarily the two extreme densities which have been considered so far. For example, in a portrait the highest density would be avoided if it represented white trimming or the reflection from a jewel, and instead the highest

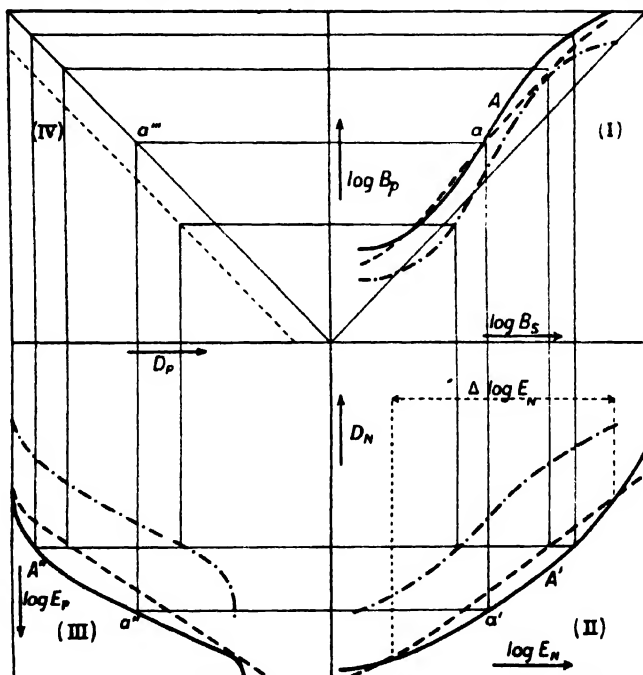


FIG. 37.3. L. A. JONES'S DIAGRAM SHOWING THE OVERALL REPRODUCTION CHARACTERISTIC THROUGH THE CHARACTERISTIC CURVES OF THE NEGATIVE AND POSITIVE

advantage in pictorial photography is to increase the value of this product to 1.3.

It is thus possible to obtain perfect objective tone reproduction by using two sensitive materials, of which the characteristic curves are not linear, if the curves show that the values of transparency, as a function of the exposure received, are symmetrical with one another about a line drawn at 135° to the exposure axis (J. F. H. Custers, 1940).

606. Calibration of Negatives. When using a well-standardized light-source, the errors and trial exposures that may be involved in choosing

half-tone which it is necessary to distinguish from the white would be measured; for instance, the lightest part of the face. In a landscape or interior having very heavy shadows, details are not always required in the shadows and the density measured would be that representing the darkest half-tone that was required to give a density only slightly below a black.

The paper to choose for a print is generally that of which the logarithm of the exposure range is equal to or very slightly greater than the difference between the densities measured on the negative. In the absence of data from

the manufacturer, this constant can be determined as follows. Using an exposure time of the same order as will be used for printing, expose a sample of the paper under a sensitometric wedge of known constant (§ 215). After processing, measure the distance in centimetres from the lightest to the heaviest density and multiply by the constant of the wedge, thereby obtaining the log exposure range required.

607. If the maximum density (or at least the greatest density that it is necessary to record) of a negative is known, it is possible to calculate the optimum printing time from the optimum time necessary for a standard negative when using the same grade of paper and the same lighting. The ratio of the two printing times is the number whose logarithm is the difference of the two maximum densities considered.

If, for example, the printing time has been 4 seconds under a density of 1.5 and the maximum density of the new negative that it is required to print is 1.0, the printing time must be multiplied (or on the contrary divided, if the new density is lower than first) by 2.5, the number whose logarithm is approximately 0.4.

The calibration or its practical interpretation, can be marked on the edge of the negative. Some printers have a densitometer arrangement for the calibration of negatives, and a method (L. Lobel and P. Prior, 1932) was devised in which the intensity of the printing light was adjusted by means of a rheostat, so that the transmission, viewed visually, of the greatest useful density, was brought to a fixed value. Under these circumstances, the printing time of all negatives was constant, when using a given printing paper.

Various inventors have proposed or made arrangements in which the exposure given by a printer is automatically regulated by a photo-electric cell receiving the total light flux transmitted by the negative (J. W. McFarlane, 1931). It is useful to consider whether this practice, obviously wrong in principle, could be considered satisfactory statistically. Important experiments directed by C. M. Tuttle (1927), who collaborated with numerous amateurs and some very skilled printers, established that if the negatives had been developed to slightly different gamma values, an exposure inversely propor-

tional to the ratio of the total light flux transmitted by the negative to the area of the image gave 94 per cent success. This was slightly better than the result obtained by skilled printers who estimated the exposure time subjectively by viewing. The degree of success would have been still greater if preliminary trials had been made from negatives of large stretches of sea and sky, for which the calibration by the procedure outlined was conducive to appreciable over-exposure.

608. Influence of the Colour of the Printing Light. The colour of the light used in printing, within the limits of spectral sensitivity of the emulsions used, has an appreciable effect on the contrast of the image obtained when the sensitive layer is coloured, or when a colourless emulsion gives a coloured image directly.

This effect, noticed by Lehmann in 1861, in the case of printing-out papers, has been explained by L. Cazes (1897). It follows that depending on whether the actinic radiations used are transmitted or absorbed by the coloured image, a certain amount of protection is given to the underlying parts of the sensitive layer. With these papers, printing through a yellow filter increases the contrast of the image slightly, while printing through a violet filter reduces it. The appropriate filters can be made by dyeing plates or films which have been fixed out, washed, and dried, by immersion for about 15 minutes in a 0.2 per cent solution of auramine (for the yellow filter) or a 0.25 per cent solution of methyl violet, rinsing and drying. (These concentrations should be halved if gelatine-backed film is being used.)

With uniformly coloured sensitive layers the effect is due to the limitations of the depth of penetration of light into the layer; the use of actinic radiations absorbed by the colouring material lowers the contrast, while it is increased by the use of more easily transmitted radiations. This effect is shown in silver-halide emulsions which have been specially dyed yellow and in all copying methods using bichromated gelatine. The sensitive layer, yellow or orange, extensively absorbs the violet and ultra-violet radiations (by far the most active) reducing the contrast when the concentration of bichromate is increased or a source particularly rich in ultra-violet is used.

CHAPTER XXXVIII

PRINTING METHODS AND MATERIALS

609. General Considerations. Printing may be done either in a printing frame or in a printing machine or box, the latter being an apparatus of varying degree of complexity, combining the printing frame with a box containing the light source.

These pieces of apparatus are essentially intended to ensure as perfect a contact as possible between the negative and the positive paper throughout the printing. They should also afford complete protection of the latter from any light other than that transmitted by the negative, and to prevent any relative displacement of the two surfaces, which would produce a double image.

The chief advantages of a printing box over a frame are that the source of light is at a constant distance from the negative, and that the dark-room is not illuminated with white light during printing. In this way many precautions which would otherwise have to be taken are dispensed with, and several operators can then work at the same time. The usual type of printer, in which the negative is illuminated by diffused light, is not suitable for printing when making duplicate negatives or transparencies on rigid supports (positive plates). Defects in the flatness of the glass never allow two plates to be in complete contact over their whole surface, and for this reason a perfectly sharp print can only be obtained if we use a small source of light, fixed in position relative to the frame and far enough from the latter for it to be considered as a point source of light.

A glass negative does not press against the glass of the frame except at a limited number of points around which there are sometimes seen by reflection coloured fringes (Newton rings) of which the outline may be recorded in the prints. The formation of these rings can be avoided by interposing a mat-surfaced film with the mat side in contact with the back of the negative.

In passing, the automatic machines for commercial printing on reels of paper should be mentioned. These are generally combined with mechanical equipment for developing, fixing, washing, and drying the paper continuously. There are also semi-automatic machines with

which a considerable number of prints can be made on paper in roll or sheet form, after which the prints are either finished on a continuous machine, or sheet by sheet in the usual way.

610. Printing Frames. The standard type of printing frame is represented diagrammatically in Fig. 38.1. A piece of white plate glass, about $\frac{1}{4}$ in. to $\frac{1}{2}$ in. (6 to 8 mm) thick and free from bubbles and scratches is placed in a hard wood frame with deep rebates. To allow for expansion of the glass when printing in the sun or near an electric arc light, there should always be an appreciable clearance between the glass and the frame. In frames used for photo-mechanical reproduction where a considerable pressure is given by levers or screws, the plate glass is replaced by a transparent slab of glass which can be as thick as $1\frac{1}{2}$ in. (30 mm). In such cases the frame is reinforced with metal. The negative to be printed is then placed face upwards on the glass support, and the printing paper, the sensitive surface in contact with the film of the negative (with or without a mask between) is placed on it. The paper is covered with a resilient pad of thick cloth, felt, or spongy rubber (failing this, several thicknesses of soft tissue-paper) and, lastly, the back, consisting of two or more hinged panels, is placed in position. The pressure-bars are then closed and fixed in position.

The back is made in hinged panels for printing those materials where a visible image is produced by the action of light directly. With a frame of this kind, the state of the picture can be ascertained by disengaging one of the pressure-bars, opening the corresponding flap, and gently lifting the pad and the paper. In small frames, where the back consists of only two pieces, it is an advantage to have the hinges a third or a quarter along its length, so as to allow of a larger part of the picture being examined. Frame bars which are automatically bolted with spring catches should also be mentioned. Again, there are certain patterns of frame with metal strips fixed to the back, which take the pressure of the spring, facilitate the manipulation of the latter, and prevent their denting the wood.

Various simplified types, for sizes up to 7×5 in. (13×18 cm), are not fitted with plate

glass, or only with thin plate or ordinary glass if they are used for printing film negatives. Their inside dimensions should then be only about $\frac{1}{8}$ in. (1 mm) larger than the negative. As the bars of such frames are usually fixed in position by turning them in a plane parallel to the back, there is always a risk of moving the back, and consequently the paper on which it is resting. Any risk of movement can be prevented if the pins of the hinges extend from the back into grooves in the frame.

For making prints of tracings on ferro-prussiate or similar papers by artificial light, when the printing can be done with a constant exposure after preliminary trials if all the tracings have been made on paper of equal transparency, a frame is used consisting of two half-cylinders of glass fixed in a metal framework. The tracing and paper are held against this curved surface with a strong linen blind or apron, which is secured by stretchers. The exposure is given by an arc lamp travelling along the axis of the cylinder at a uniform controllable speed, the light being thus used with maximum efficiency. Tubular lamps fixed on the axis of the cylinder are also used. In large studios, continuous machines are also used, the tracings and papers being carried along over a half-cylinder of glass by an endless belt, moving at a speed adjusted to the sensitivity of the paper. These machines are sometimes used in conjunction with a machine for the processing and drying of the paper.

For printing from large plates or negatives, particularly in photo-mechanical work (photogravure, photo-lithography, etc.), and whenever it is necessary to ensure the most perfect contrast, a pneumatic printing frame is used, which takes the form of a rubberized fabric apron bordered with a frame of grooved soft rubber, which is pressed against the glass of the printing frame by means of another frame. A metal tube, connected to the apron, allows the space between it and the glass to be exhausted, the sensitive surface being thus held against the negative by atmospheric pressure. The pressure being thus balanced on the two sides of the glass, allows it to be much thinner than in mechanical frames, thus reducing the absorption of the violet and ultra-violet radiation.

611. Printing Machines. Printing on develop-

ment papers in a professional or industrial studio is always done by means of a printing machine. Since their introduction in about 1900, a large number of types of this instrument have been made, some of them being semi-automatic machines driven by an electric motor.

Printing boxes designed for the printing of glass negatives consist essentially of a horizontal glass plate at a convenient working height, which carries the negative to be printed, and a pressure plate which a lever, operated by hand or foot, holds in place automatically at the end

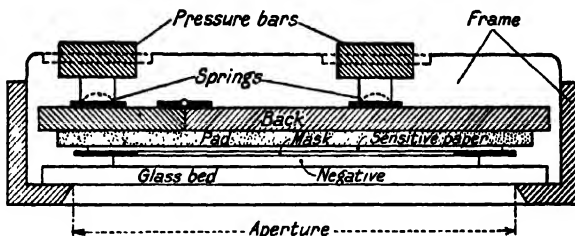


FIG. 38.1 PARTS OF A PRINTING FRAME

of its travel. The box of the printer, light-proof but amply ventilated, contains one or several printing lamps, or one lamp and a mirror system to ensure even illumination, according to the size of the frame. There is also an orange or red lamp which facilitates the adjustment of paper, negative, and masks.

The pressure lever operating the back of the frame is attached to a switch, which, when the back is under pressure, switches on the printing lights. On releasing the lever the lamps are switched off again.

The printing lamps are sometimes controlled by means of a timer, which regulates the duration of exposure to that desired, by means of a clockwork mechanism, the passage of air or glycerine through a small orifice, or an electronic device based usually on the discharge of a condenser (which is always charged to the same conditions) through a variable resistance. It has been suggested (M. McIntire, 1920) that where variations in the supply voltage are frequent and of large magnitude, the variations in illumination could be approximately corrected by using a timer controlled by an electric motor, so that an increase in voltage raised the motor speed, thus shortening the exposure. On some printers the pressure lever is released electromagnetically when the white light is switched off by the timer.

In order to allow of modifying the illumination on the various parts of the negative by the interposition of suitably-shaped pieces of translucent paper, the printer is usually fitted with a sliding frame just underneath the glass negative bed. This frame is fitted with a piece of ground glass on which any shaped pieces of paper may be placed as desired. Besides regulating the exposure times, nearly all printers allow of the illumination being varied at will by altering the distance between the lamps and the diffuser. In this case a number of suitably scaled positions should be marked out, corresponding, for example, to illuminations which



FIG. 38.2. FAULTY CONTACT OF
PRESSURE BACK

increase in steps of 2 : 1. Again, it is useful to be able to control the various white lamps separately, or to move them in a plane parallel to the diffuser, so that the illumination in various parts of the negative can be altered.

Instead of controlling the exposure time, some printers employ control of the illumination, by vertical displacement of the lampholders against a scale, or by means of a rheostat in series with the lamps, being calibrated such that moving from one position to the next doubles the light. The latter system has several disadvantages: it is necessary to allow not only for the variation in intensity of the light but also its quality, the colour-temperature of the lamp being lowered when the series resistance is increased; the resistance of both the lamp and rheostat vary with temperature, and while the rheostat takes a long time to reach its steady temperature the lamp does not, thus causing the intensity to vary for some time after each adjustment. Another disadvantage is that the effect of supply voltage fluctuation is increased, owing to the fact that the resistance of the lamp varies more with current than that of the rheostat, a change of 10 per cent in a supply voltage of 110 V, for example, causing a change of 13 per cent in the voltage across a lamp running on 60 V.

The beds of some printers are fitted with a number of stops which can be removed at will, and which allow a suitably-sized sheet of sensitive paper to be adjusted to such positions that six or twelve pictures can be made in succession on it from the same negative. If the exposure is automatically regulated by the printer, one

can be certain that the prints will develop up identically, and consequently the images will be the same. Other more complicated types are fitted with a movable carriage which carries the sheet of paper and stops automatically in predetermined positions. Lastly, there are printers which are provided with spools for making separate prints from film negatives in the whole strip, the film being moved for each successive exposure.

Blurred patches, caused by defective contact, and often noticed on prints which have been made in a printer, are frequently due to insufficient pressure along the join between the two halves of the back. If there is excessive pressure on the sides of the latter, the defect is accentuated by a thick negative of very small size (Fig. 38.2). This difficulty can be overcome by placing the negative in a cardboard frame of about the same thickness as the negative. Blur which occurs in different positions in successive prints from the same negative is often due to air pockets formed between the sensitive paper and the negative when the pressure pad is not slightly convex. This fault can often be avoided by passing the back of the paper over a hard wooden edge in such a way as to make the sensitive surface slightly convex.

612. A standard for printers adopted in 1942 in the United States requires that the illumination at the sides of the frame should not be less than 65 per cent that at the centre, and that local irregularities should not exceed 15 per cent over a length of one inch. Good contact during printing is verified by printing a graticule of 1,200 lines per inch. After an hour of continuous use, exposures of 10 seconds being separated by pauses of the same duration, the temperature should neither rise by more than 40°C nor become higher than 65°. If the mask is placed between the negative and the paper it should not exceed 0.005 inches in thickness, or 0.02 inches if between the negative and the glass plate of the printer. The angles between the sides of the frame should be within 0.10° of a right-angle.

613. **Commercial Printers.** Printers especially designed for the printing of film negatives, and particularly those used in establishments catering for amateur work, usually have the glass plate inclined slightly (like a desk) in order to make work easier for a seated operator and to avoid the accumulation of dust. This inclined part is often extended by a chute which deposits the prints in a drainer or directly into the developing dish.

The prints are usually numbered on the printer with the order number. The automatic numbering device is mounted on the pressure pad of the printer and should only exert a very slight pressure; it is desirable that the numbering should take place before exposure although it is on the back of the print, to avoid the risk of the number appearing in white on the image (it was shown by Ny Tsi-Zé in 1933 that the speed of a sensitive emulsion is lowered during pressure).

With semi-automatic motor-driven printers, the number of prints per hour is about 400 to 500, from the same number of negatives, but if the number of negatives is small, as many as 1,500 prints can be made per hour. In these machines the exposure is selected by a press-button, which also starts the motor, either varying the time of exposure or the light intensity. The various operations are then performed automatically; the pressure plate closes, the desired exposure is given. The pressure plate opens and the sheet of paper is ejected, after which the motor stops in readiness for the next operation. It is also possible to arrange it to work continuously, pausing for long enough for a fresh sheet of paper to be put in place and stopping after a pre-determined number of prints.

These printers often allow negatives to be printed from a strip of film without having to cut it up, slots being provided for the passage of the strip under the pressure plate.

614. Light Sources for Positive Printing. Incandescent electric lamps are generally used for printing and according to the sensitivity of the papers usually employed their intensity should be neither too great nor too small. It is better to use "pearl" or frosted lamps to prevent uneven illumination due to reflection or refraction from the glass. In this way both very short exposures, which are difficult to time and repeat correctly, and long exposures, which slow down the work, are avoided. The fact that the distance between the lamp and the negative has a considerable influence on the illumination (§ 11), and consequently on the exposure, should not be overlooked. To avoid too considerable local variations in illumination, the distance between the source of light and the negative should never be less than the diagonal of the negative.

For printing on plates it is preferable to use only one lamp, of sufficient intensity to enable its distance from the negative to be great enough to render the illumination substantially

uniform. It is sometimes possible, by suitable choice of lamp distance, to compensate for greater exposure at the centre of the negative resulting from uneven light distribution in the image plane of the camera lens.

The supply voltage varies very considerably at different times of the day, being generally at a maximum in the daytime and at a minimum at dusk. As variations in the voltage considerably influence the visual intensity of the emitted light and also its colour temperature (§ 313), it is advisable to keep a voltmeter in the printing room, so that, as the result of a few tests, the voltmeter can be graduated in terms of equivalent exposure, arbitrarily assigning the value 1 to the exposure corresponding with the normal voltage. A better, but more expensive, system is to use some form of voltage stabilization, either a saturated-core transformer, if A.C. is available, or an electronic voltage-regulator, to supply the printing lamps.

615. Actinometers and Light Integrators. When using sensitive materials, such as carbon tissue, which do not allow the degree of exposure to be judged by the eye, the time of exposure to light is still sometimes regulated by means of an actinometer. In this way the quantity of actinic light received by the frame may be approximately determined.

A strip of sensitive print-out paper is exposed under a density scale in a small printing frame. The density scale may consist, for example, of about ten thicknesses of translucent paper placed on top of each other, each piece being about half an inch shorter than the preceding one. The number of superimposed thicknesses is then marked on each step of this scale with indian ink (or any other opaque ink which is without action on the sensitive surface). After exposure to light for a certain time the number of figures which appear light on a ground of greater or less depth can be read off on the test strip.

In preliminary trials for the determination of the correct exposure, this actinometer is loaded with a fresh strip of paper, and the whole placed by the side of the printing frame, both facing the same way. When printing is stopped, the last readable number on the strip is noted. In this way an equivalent exposure can be made at any time, or the exposure adjusted as required, by exposing the frame for the time required for the same number to appear on the actinometer. The relationship will hold good as long as the strips of sensitive paper are of the

same make (and batch), and undergo no change or deterioration.

The fact that bichromated film and silver-sensitized paper are not affected proportionally by very weak and very strong illuminations is sometimes raised as an objection to this method. It can be overcome by using, instead of silver-sensitized paper, white note paper which has been sensitized in a 3 per cent solution of ammonium bichromate and dried in the dark.

Another type of actinometer, which has to be watched during the whole exposure is sometimes used. Two long pieces of glass, about 1×10 in. are held together by strong rubber bands, after a piece of opaque paper has been gummed on the inside covering the whole of one and all but half-an-inch of the other of the pieces of glass. A strip of bichromate paper is placed between them, with one end slightly protruding from the glass, and the whole exposed to light until the part which is protected only by the glass has turned as brown as it will go. To use this actinometer, the sensitive strip is drawn out a little way, and the time which the fresh portion takes to acquire the tint of the previously darkened portion is taken as unity (*degré Arigue*), after which a fresh section of the paper is pulled out, and so on.

In industrial installations these exposures are controlled by placing the photo-electric cell of a light-integrator alongside the printing frame and in the same plane as the sensitive surface.

616. Styles of Printing. A negative may be *printed in solid*, the paper being entirely covered by the picture (at least after trimming), or *printed behind a mask*, so as to leave narrow or wide white or tinted margins, or, again, *vignetted*, the image tones passing imperceptibly from their full intensity to the tone of the paper.

It is possible to improve some parts of the picture during printing by local variations either of the illumination or of the exposure. In this way the effect of *working-up* the negative can be supplemented, or dispensed with altogether.

There are various methods by which too great a sharpness of the image can be avoided, the effects of a sharp and diffused print being proportionally combined as required (§ 568), while excessive contrasts in a photograph can be lessened by breaking up the uniformity of the masses of shadows.

Images can be combined in various ways, such as the introduction of a background or sky after the usual printing, surrounding the picture with a toned border, or in other ways.

617. Signing Prints. Prints made on development papers can be signed before development. For a signature in white on a dark background, either a 10 per cent solution of potassium iodide can be used with a metal pen or a 1 per cent solution of potassium permanganate with a glass pen. The surplus is rinsed off before development. The latter has an advantage in that excess is destroyed by the gelatine, and thus the risk is removed of the signature being blurred in the rinse; it is, however, necessary to add a little bisulphite to the rinse to dissolve the manganese dioxide liberated. For a signature in black on a white background, or in the border, write on the print with a stylus of the type used in preparing stencils for duplicating machines, the signature resulting from abrasion; this is not usually possible with glossy papers, though, as they are usually protected against abrasion by means of a supercoat of clear gelatine.

618. Printing behind Masks. The masks used to protect the sensitive paper during printing are generally made of black paper free from pinholes or thin parts, sometimes of very thin red celluloid, or sheets of tin-foil. Celluloid has an advantage in that it can be adjusted more easily on the negative, the image being visible through the mask. Foil is seldom used except in certain processes of photo-mechanical reproduction where the print is on a rigid support. It can be used very much thinner than celluloid or even paper, and there is less risk of blurring being caused by bad contact.

Cut-out masks can be bought in various shapes and sizes—rectangles with rounded corners, ovals, circles; also fancy shapes, the use of which is not always pleasing. Such masks are usually supplied with their corresponding opaque counterparts or *counter-masks*. The counter-masks can be employed to obtain black margins on a print which has been already fully printed, by means of a second exposure, the print being exposed under the counter-mask.

A mask may also be cut out with a penknife to any required shape, or, if a rectangular opening with sharp corners is required, it can be made by sticking strips with clean-cut edges on to the gelatine surface of the negative itself.

When printing from film negatives, the mask may be inserted between the negative and the glass of the frame instead of between the negative and the sensitive paper. A mask can be fixed temporarily to a negative (to avoid relative movement) by a spot of rubber solution

on each corner. It can afterwards be rubbed off both negative and mask with the fingers.

In photographic establishments where amateur's work is undertaken, it is the practice to supply the print with a narrow white margin, without, however, any trouble being taken to select the best opening or the most suitable position for the mask on the negative. In such cases a *frame mask* or *border mask* is generally used. One side of the mask is covered with a

positions on pieces of glass slightly larger than the sensitive paper to be used; the position of the latter is exactly determined by means of a "square" cut out of thin card and fixed along two sides of the glass to serve as a stop.

For printing from glass negatives the masks should be fixed in a cardboard frame, with an opening to fit the negative, which is held in place by strips of gummed paper, the gelatine surface of the negative being towards the mask, while

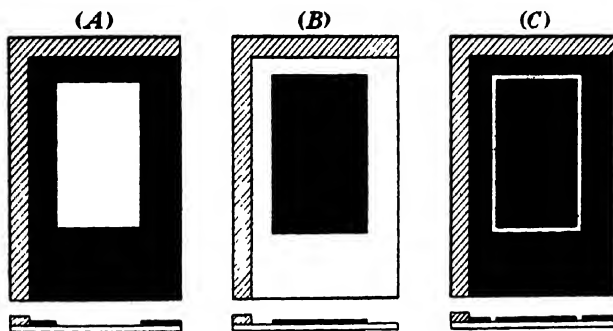


FIG. 38.3. BORDER PRINTING

A, mask; B, counter-mask; C, combined mask and counter-mask

thin card, cut out to the size of the negative, which is thus automatically centred on the opening. When a border mask is to be used for printing on large-sized paper or card, e.g. for printing small negatives on postcards, the paper may be adjusted more easily in the opening if another cut-out card is used, or clearly visible register marks are made on the existing mask.

619. Printing with a Tinted Border. Pleasing effects may be obtained by surrounding a picture which has been printed on a larger size of paper with variously-sized borders or edgings in grey of different densities. These effects can be obtained by means of a combination of masks carefully cut and accurately marked in relation to the sensitive paper.

In Fig. 38.3, *A* and *B* represent a mask and counter-mask respectively, the latter being of slightly larger dimensions (from $\frac{1}{8}$ in. to $\frac{1}{4}$ in.) than the opening in the former, so that, when printed under a negative, a print is obtained with wide margins, which, with the exception of a thin white edge (about $\frac{1}{8}$ in. in width), will be made a light or medium grey by a short exposure under the counter-mask.

For printing film negatives both the mask and counter-mask should be stuck in corresponding

the "square" edge serving as a stop for the paper is fixed on the other side.

Before such border masks are mounted, the outlines of the picture and of each frame to be used should be drawn on a piece of stout paper. The attachment of the mask and counter-mask should be done by the aid of this guide-piece, one of the outlines being made flush with the side of each piece, after the guide-piece has been thrust as far as it will go into the cut-out square.

Surrounds of several borders of different tones can be easily designed, and effects similar to those obtained by multiple mounting with superimposed papers thus obtained. Instead of a piece of plain glass fixed to the counter-mask, it is possible to employ a negative reproducing the texture of a material such as coarse canvas. Muslin or net can also be stretched on the glass.

620. Local Control During Printing. The effect of retouching or other work on the negative may sometimes be completed or supplemented by holding back the printing of certain parts of the picture.

If, when using a printing frame, a suitably shaped piece of cardboard is held in the hand

at a little distance in front of the frame during a part of the exposure to light, its shadow will be thrown on those parts of the picture which it is desired to hold back. To prevent a sharp outline of the cardboard appearing on the print, it should be kept slightly moving to and fro, either in the same plane as the cardboard or perpendicularly to its own plane. A frame with a translucent back has been used, so that the position of the shadow on the picture can be ascertained from the back of the frame.

621. Reduction of Definition and Contrast.

At the time when most prints were made on printing-out papers, a special printing frame for the reduction of definition and contrast, developed by E. Artigue (1903) was put on the market. It enabled a thin positive transparency made from the same negative to be placed between the print and the negative for part of the exposure time. With a few precautions, this means of reducing contrast and definition can also be applied to enlarging. A variation of it, due to J. A. C. Yule (1944) gives an increase in the contrast of fine detail, particularly applicable to photographs of surface structure. A slightly unsharp positive transparency made by contact printing, is placed on the negative, in register, during contact printing or enlarging. For instance, the negative can be developed to a much higher contrast than that which allows printing on the softest paper, and reduced to a normal contrast by means of the superimposed positive ($\gamma = \gamma_N - \gamma_P$). The fine details, which are not resolved by the positive, retain their initial contrast, the positive only superimposing a uniform density on them.

The writer recommends, for printing the positive, that a thin sheet of cellulose acetate (portrait film with the gelatine removed) be put between the negative and the positive material. The best softness is obtained by offsetting the printing lamp from the axis of the printing frame by a distance of $\frac{1}{10}$ its distance from the frame, and rotating the printing frame in its own plane; when the final print is to be made by contact, place the lamp as far from the printing frame as possible; when the final print is made by projection or in a camera this distance should be equal to the distance from the lens to the negative in the final printing.

In the limiting case where the gamma of the unsharp positive is equal to that of the negative, all the tones of the subject are reproduced as whites and only sharp changes in tone become invisible, the result resembling a pen drawing.

622. In printing from a negative of relatively large dimensions, the sharpness can be reduced by combining a sharp image with an unsharp one.

The sensitive paper is fixed to a support by gummed strips or heavy metal weights, (which can rest on a mask) against which the negative may be butted. For printing without borders the paper and negative can be butted against pins driven into the support. A piece of frosted film or glass is placed on the paper, frosted side upwards, and the negative, emulsion down, in place on it, being held down by a piece of heavy glass free of flaws. A first exposure is given by means of a lamp about 5 ft from the negative. After this exposure the frosted material is removed, the negative replaced against the stops and a second exposure given, after which the print is developed. Depending upon the proportion of each exposure (taking into account the difference introduced by the frosted material, which need only be determined once) the amount of diffusion introduced can be controlled as desired.

If the negative is fixed to a wide-bordered mask, and is being printed on to paper with inside borders by means of diffused light, a sheet of celluloid or cellulose acetate of suitable transparency can be placed between the negative and the paper for part of the exposure: in order to do this the paper can be held firmly on to the mask while the film is inserted.

623. Combination Prints—Insertion of Backgrounds—Adding a Sky to a Landscape. It is not possible to consider here every case in which a photograph can be "faked" by the photographer, for example, by introducing a figure into a group or scene, or by inserting into a landscape a foreground from another negative. These combinations are always made by cutting out the parts of the print to be transferred, thinning the edges of the paper, and sticking them on the print of the group or landscape, concealing the joints by a little retouching and finally photographing the composite picture.

It should be noted here that the perspective must be adequately considered, and that only images of the same lighting, contrast, and tone can be thus superimposed.

Three operations which occur relatively frequently will only be considered here, viz., grouping of several portraits in one photograph, putting a background into a portrait, and adding clouds to a landscape.

In order to print several separate portraits (members of the same family, or one person in several different poses), vignetted on a white

background, on to the same sheet of paper, make a model by assembling prints from the various negatives on a glass plate of the same size as the paper to be used. These prints, made on thin paper, should be stuck to the glass by their backs.

Frames of thin card, cut out so as to receive this glass plate with little play, are then fixed to each of the negatives such that, the model on glass being placed in the frame, emulsion to emulsion, the image on paper coincides exactly with that on the negative. Each subject is then printed in turn by placing the sensitive paper in the appropriate frame.

Film background negatives are sold which reproduce the standard types of professional backgrounds (draperies, cloudy backgrounds, various interiors) of which the central portion is either completely transparent or completely opaque. In the first case the masks are superimposed on a portrait negative which has been taken in front of a plain and very dark background, the background and the subject being afterwards printed at the same time. In the second case, after exposing the paper under the negative of a portrait taken with a uniform white background (or blocked out afterwards to hide a defective background), it is exposed under the background negative, suitably proportioning the two times of exposure.

624. The use of a panchromatic emulsion and an appropriate filter usually allows the sky in a landscape to be recorded quite satisfactorily, but the image of the sky on a non-colour-sensitized emulsion is nearly always so over-exposed that it is represented by white paper on the print. It is possible, however, that the sky be a uniform blue or grey at the time the photograph is taken. The print can be improved by giving the sky extra exposure so as to shade it slightly to a darker grey at the top of the print, but for the purposes of composition it is often very useful to fake some clouds. To do this, the sky from another negative is used, it being essential that both negatives are made under the same lighting conditions (i.e. height of the sun and its direction relative to the camera). A sky which is too dark should always be avoided, because, except during a storm, the darkest parts of the clouds are always lighter than the shadows in the landscape.

Before proceeding with the printing a mask is made to cover the portions of the sky negative which would be printed on to the landscape. Its counterpart is sometimes used to mask the

sky on the landscape negative. This mask is best made from a print of the landscape negative made on print-out paper, by cutting it out with fine embroidery scissors. The two parts are then exposed to light until uniformly darkened. The mask of the sky is then attached to the landscape negative, and the landscape mask to the sky negative, by means of a few spots of rubber solution. This operation is best done on a sheet of glass lighed from beneath. The two printing operations are then done by diffused light.

A sky may be added to a transparency more simply, by printing the cloud negative on a second plate, which afterwards takes the position and place of the usual cover glass. The direction of the light in the cloud negative must be chosen with regard to the fact that the picture is reversed. This method allows an excessively dense sky to be corrected if necessary, by reduction, and simplifies the register of the two pictures. A sky may also be transferred to a positive transparency without any difficulty by the aid of a stripping positive paper.

625. *General Hints.* The glass of the frame or printer should be carefully cleaned on both sides, and the felt pads brushed before work is begun. The back of the negative should also be cleaned, if necessary.

Carefully place the negative correctly in the frame, with the gelatine side away from the glass support. Fix the mask, if any, in position and then the sensitive paper or plate, the sensitive side in contact with the negative, avoiding all contact of the fingers with the surface; keep the whole in position by pressure with the hand while the first part of the hinged back is fixed in place.

To avoid errors in the number of prints to be made count out the required number of sheets of sensitive paper and place them in a separate box at the beginning.

In exceptional cases, where it is necessary to make a print from the reverse side of a film negative, or even from a glass negative, parallel light or light from a point source at a great distance from the frame should be used. When printing by artificial light, the source of light should be as small as possible, and the frame placed as far from it as is convenient without prolonging the exposure excessively. If an enlarging or projection apparatus which is fitted with a condenser is available, an almost parallel beam of light can be obtained by suitably adjusting the light source. Printing can then be carried out nearer the lamp and with considerably shorter exposures.

CHAPTER XXXIX

ENLARGEMENTS

626. General. A negative can be enlarged either directly, by projecting on to a positive sensitive surface an enlarged image of the negative, or indirectly by first making a positive transparency of the same or slightly larger dimensions as the original negative, and then an enlarged negative from which the final prints are made by contact.

As a curiosity, mention may be made of a method suggested on several occasions (C. Scolik, 1895) and which has recently (1949) been revived in the U.S.A. for making paper prints from colour transparencies. This consists of enlarging the original negative by expansion of the gelatine film (§ 582) without previous tanning. Such a method is necessarily very uncertain, and it should be noted that if the negative is enlarged n times the densities (and in consequence the contrast also) are reduced in the proportion n^2 to 1.

As a rule, the direct method is chosen when only a limited number of enlarged copies of one subject are to be made on bromide paper. The indirect method is preferred for the production of a large number of identical enlargements, and it is the only practical one if the enlarged prints are required on papers of low sensitivity, such as carbon and platinum papers.

An improper application of the *principle of the reversibility of rays* (§ 63) has often led to the recommendation to employ, when making an enlargement, the same lens with which the negative was taken. It is not possible to expect even the correction of distortion by this means, because the negative does not occupy the same position in relation to the lens that it had in the camera except when the enlarged image is of the same dimensions as the subject photographed, which is not generally the case.

With the large number of enlargers which are now available it is usual and, in fact, preferable to use a lens which has been specially designed for working at the distances such as are common in this type of work. The corrections required in an enlarging lens are more nearly the same as those required in copying cameras and process cameras than lenses computed for ordinary photographic work. The subject matter is flat and the ratio of image distance to object distance seldom exceeds 10 to 1.

627. Enlarging with Condensed and Diffused Light. Very different results, particularly as regards the contrast of the image and the prominence of minute defects in the negative, are obtained depending on whether the negative to be enlarged is illuminated by a beam of light coming from the source and caused to converge into the lens by an appropriate optical system (the condenser), or whether the negative is illuminated by a uniformly diffused light.

Other working conditions being the same, the contrast of the image is always greater in the print enlarged with a condenser than in a print enlarged by diffused light, and at the same time retouching and the minute defects on the negative are emphasized, owing to the increase in their contrast with the parts of the image where they appear. In an enlargement made by diffused light the contrast of the image is much the same as in a contact print from the same negative on the same sensitive material. The small surface defects are not more pronounced, except as regards their size, than in the contact print. The variation in contrast when passing from "directed" light to diffused light is somewhat decreased when the lens aperture increases (H. Bäckström, 1921; G. Boutry, 1934).

When the same negative is enlarged in different types of enlarger, equivalent results have been obtained with papers of which the logarithm of the range was—

Directed light (clear bulb, condenser)	1.1
Opal bulb and condenser	1.0
Clear bulb, opal diffuser	0.9
M-tube mercury vapour lamp and ground glass	0.8

In a beam of directed light, the most transparent parts of the negative are non-scattering, or scatter only slightly, and thus deviate from its normal path only a negligible fraction of the light transmitted. On the other hand, the densest parts are highly diffusing, and scatter in all directions an appreciable part of the light which has penetrated them. Nearly all this scattered light fails to reach the lens, and consequently the dense parts have an apparent density greater than their actual density with a resultant increase of contrast.

In a negative illuminated by completely diffused light, that is a negative of which each point receives light at all possible angles of incidence, there is a balance between the light which is travelling towards the lens before reaching the negative and is scattered by the latter, and the light which has reached the negative at other angles and is likewise scattered in the direction of the lens.

The first study of this phenomenon was made by A. Callier in 1909, hence the name of *Callier effect* sometimes given to it. This investigator showed that the densities in condensed light for a given negative are equal to those in diffused light multiplied by a constant factor. Since then it has been recognized that the relation between these two values of density is considerably more complicated. F. F. Renwick and O. Bloch (1916) have found that the relation between the two densities D_* in diffused light and $D \parallel$ in directed light is of the form: $\log D \parallel = a \log D_* + b$, the values a and b varying from one negative to another according to the emulsion used and the methods of treatment.

With a negative of which the densities measured in diffused light ranged from 0.40 to 1.90 there was found, with directed light, densities of 0.78 to 3.53 which range no paper is capable of recording.

The various factors that reduce the scatter of light by the surface of the negative to be enlarged, e.g. varnishing or immersion in a liquid, will also reduce the effect of superficial defects (scratches, retouching, etc.) but will increase the contrasts of the image (C. Winther, 1922). It is easy to see that varnishing confined to certain parts of the image (parts treated with retouching medium for subsequent retouching) leads to markings with well-defined outlines.

All factors increasing the scatter of light by the silver deposit will obviously exaggerate the differences in rendering due to the two methods of illumination. These differences are more marked in the case of a negative of coarse grain than with a negative of fine-grain emulsion.

Enlargement with a condenser requires a new adjustment of the light source for each variation in the scale of enlargement. To avoid these many adjustments, a sheet of ground glass is sometimes fitted between the condenser and the negative to be enlarged. The ground glass is thus uniformly illuminated, and its scatter is predominantly towards the lens, this action and the consequent increase in the amount of light passing the lens being then the sole advan-

tage of using the condenser. The results thus obtained differ little from those with uniformly diffused light.

Finally, the graininess of the negative image is very much less apparent in prints enlarged by diffused light than in prints enlarged with a condenser. It is often found that an enlargement of 10 times with diffused light shows less grain than one of 3 times with directed light. The cause of these differences is easy to understand if it is borne in mind that, in enlargement with directed light, the image of a point is formed by a narrower pencil of light rays. A black patch will therefore be produced in an area of light tone if a part of this pencil has been able to pass between several clumps of grains. In enlargement with diffused light, where all possible directions of the incident light have united in forming the image of a point, the chances that some light-rays can pass freely between the clumps of grains are nearly the same for all points of the image.

Using a condenser enlarger, it is possible to obtain effects similar to those produced by a diffused light enlarger by inserting an opaque stop into the lens so as to block out the central zone (E. W. H. Selwyn, 1943). Systematic experiments undertaken by the same author showed that the graininess of an enlargement made in condensed illumination was 2.5 times that of an enlargement made by diffused lighting, the working conditions being adjusted so that the two enlargements obtained were identical, with the exception of the graininess.

628. Negatives Best Suited for Enlarging.

The graininess of a negative being always greater as the densities are higher (L. A. Jones and N. Deisch, 1920), it is necessary to avoid all circumstances likely to increase the density of the image uselessly, e.g. over-exposure, fogging of various kinds, over-development (since with nearly all developers graininess increases much more rapidly than density) and all factors which may cause incipient reticulation, such as a too warm developer, a warm fixing bath not containing a hardener, and prolonged washing in hot weather. If the water available is highly charged with minerals, precautions must be taken to avoid any deposit of lime on the negatives. Care must also be taken to avoid dust settling on the negatives during drying.

The increase of contrast when enlarging with a condenser is of value in enabling the best use to be made of correctly-exposed and somewhat under-developed plates. Such negatives are also

suitable for enlargement by diffused light on contrasty papers.

Negatives which have been retouched or negatives with small defects may usefully be varnished, being then best enlarged by diffused light.

629. Loss of Detail in Enlarging. Multiple reflections between the various air-to-glass surfaces (lenses of the objective, glass plates between which the negative is placed) contribute a general fogging of the enlarged image and a loss of contrast which is particularly noticeable when a contact print is compared with an

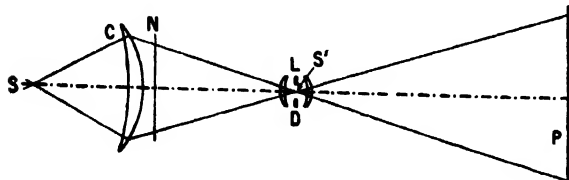


Fig. 39.1. IDEAL OPTICAL SYSTEM OF CONDENSER ENLARGER

enlargement made by diffused illumination. The loss of contrast, moreover, cannot be completely compensated for by using a more contrasty paper; this will not restore the detail lost due to the illumination.

This loss of contrast can be best avoided by the use of a mask which covers all but the area of the negative being used. It is particularly necessary to mask off all light passing round the negative and through the transparent rebates of the plate holder.

The heating effect on the negative, resulting from a long exposure, can be reduced by using as a mask not black paper, which absorbs much of the radiation, but thin aluminium or tin foil which reflects it.

It is useful to know, for a given enlarger, the relation between the density steps of a contact printed copy of a step wedge made on the negative material normally used and enlargements from the same step wedge made on different grades of the same paper. In this way, it is possible to make a reliable choice of the grade of paper which must be used to enlarge a negative from which a perfect contact print has been made on a certain grade of paper.

630. Enlarger. The most logical classification of enlargers, apart from the consideration of their illumination system, whether it be diffused light or condenser, is into vertical and horizontal types.

The vertical enlarger is popular, especially with amateur photographers, because it takes up less space than the horizontal type, size for size, and is far more convenient to use.

In spite of the inconvenience horizontal enlargers are still in use, since they have a flexibility which the vertical enlarger lacks, and the maximum size of enlargement of which they are capable is, under favourable circumstances, unlimited.

Optically these two types are identical, the vertical enlarger being simply a horizontal enlarger standing on its easel. The choice of enlarger must inevitably remain a matter of personal taste.

The growth of miniature negative photography has brought into being new patterns of enlargers, intended for the photo-finishing establishments. Their appearance and method of use resembles that of contact printing machines. These enlargers are of fixed focus or only allow of a small number of pre-set magnifications. The

arrangements for controlling the exposure are very similar to those used in semi-automatic printers. Pressure on one of a series of keys controls either the length of the exposure time for a constant intensity or the intensity of the light for a constant exposure time. Exposure may be automatically set by means of a photo-electric cell.

ENLARGEMENTS BY DIRECTED LIGHT

631. Principles of Enlargement by Directed Light. Let us consider a lens L (Fig. 39.1) and a drawing on glass N placed perpendicularly to the optic axis, in such a position that a sharp and enlarged image of N is cast by the lens on the plane P . Let us assume that at C , on the other side of N , there is an achromatic and aplanatic convergent system, the optic axis of which coincides with that of the lens, and that at S , on the optic axis common to the system, there is a point source of light, of which the image, also reduced to a point, is formed at S' at the centre of the entrance pupil.

Under these ideal conditions, which can never be completely realized in practice, the lens could, without any disadvantage, be of poor quality (or even absent) without affecting the qualities of the image (or shadow) projected at P . The drawing N is, in fact, projected on P from the projection centre S' , as the beam issuing from

the condenser C is assumed to be aplanatic. Each point of the drawing N is traversed by one ray only, and in particular the intensity of the image formed at P is entirely independent of the size of the stop D . In the case where the image S' of the light source does not coincide with the centre of the entrance pupil, the sole effect of a gradual closing of the stop D will be to intercept some of the more oblique rays, thus limiting the extent of the part of the plane N of which the image is projected at P , but without affecting the intensity or the sharpness of the central area remaining.

Barring very rare exceptions (reproduction of a line drawing perfectly free from veil), the negative or positive placed at N is more or less a scatterer of light. The whole of the light emerging from such a negative or positive is no longer directed; a fraction of this light is scattered and therefore covers the whole aperture of the lens. The combination of condenser and lens does not therefore usually form a single optical system, and therefore its "optics" call for somewhat detailed consideration from the practical standpoint.

Ordinary condensers, made of roughly-moulded lenses, are neither achromatic nor aplanatic; and, moreover, the light sources employed for enlargement or projection are never point sources. There is therefore no point of assembly S' of all the rays issuing from the condenser, but merely a concentration of the beam on a surface, which is greater as the source of light is larger and the aberrations of the condenser are more considerable. It may be noted that a poor lens used with an aplanatic condenser can give a better image, especially with a negative or positive which does not scatter light, or only does so slightly, than a perfect lens used with a bad condenser.

In the conditions which prevail in practice, the case is intermediate between illumination by directed light and illumination by diffused light, but with a marked predominance of directed light. From each point of the image there emerges a cone of rays which more than covers the whole surface of the lens, but with an intensity predominating round the straight line joining the centre of the entrance pupil to the point in question. If the lens is of poor quality, stopping down may then improve the definition a little in the centre of the projected image, reducing the intensity very slightly. But its chief effect is to intercept the best part of the beams forming the image of the margins, only

the diffused light being retained, and the consequence of this is to restrict the field which is uniformly illuminated.

Whereas, under ideal conditions, the illumination of the image would depend solely on the intrinsic brilliancy of the light source used, this is not the case in practice. The brightness of the light is not the sole factor, although its influence is still dominant. For instance, if a lamp with a certain size filament is replaced by another of twice the linear size, giving four times the illuminating surface, the illumination of the image will not be more than doubled at the most. It is sometimes of advantage, from the point of view of the sharpness of the images, to stop down a light source of large size in spite of the slight loss of light resulting from the elimination of the portions of the light farthest from the optic axis.

632. Condensers. The condenser is usually formed of two identical plano-convex lenses the poles of which are almost in contact.

As the pole of a plano-convex lens is the nodal point for the space towards which the convexity is turned, it will be seen that the *interspace* of the combination (§ 70) is equal to the distance between the poles, usually $\frac{1}{8}$ in. The resulting focal length is therefore very little different from half the common focal length of the two elements, the nodal points of the complete system dividing the total thickness of the condenser into about three equal parts. The aberrations of such a condenser are at their minimum when it can be used symmetrically, the light-source and the entrance pupil of the lens then occupying the focal planes of the single plano-convex lenses.

The following table lists the characteristics of the usual two-lens condensers—

Diameter of lenses (mm)	102	125	150	200	250	305
Thickness of lenses (mm)	22	30	32	38	40	60
Focal length of condenser (mm)	70	85	125	155	190	250

Occasionally condensers are used of which the components, named in their order, starting from the light source, are a converging meniscus (concave surface turned to the light) and a bi-convex lens, or a converging meniscus (turned as in the preceding case) followed by the two plano-convex lenses of an ordinary condenser. As the focal length of this *triple condenser* can be shorter than that of an ordinary condenser of the same diameter, the light-source can be brought nearer, thus utilizing a larger portion of the light emitted.

It is easy to get a clear idea of the magnitude of the aberrations of a condenser by examining

the shape of the beam issuing from the condenser by arranging a dark background behind the beam and blowing smoke into the latter. Or the beam may be cut along its axis by a plate of mat aluminium on which the caustic (envelope of rays of light) appears very clearly and can be photographed. This experiment enables a clear idea to be obtained of the effect of the size and position of the light source.

For a more exact test of a condenser, the light source is replaced by an opaque screen of the same size and shape as the light. This is stuck on to a diffusing screen, e.g. ground glass which is illuminated as uniformly as possible. If the condenser is perfect and perfectly adjusted (§ 633) the easel will be uniformly dark when viewed in the ordinary way. All parts of the easel which are illuminated under these conditions correspond to zones of less illumination in normal working (L. T. Beechlyn, 1922). We may also mention the development of aplanatic condensers, including at least one surface of non-spherical curvature, up to diameters of 25 in. (L. V. Foster, 1926), and of condensers with zonal aberrations adjusted so as to attenuate the falling off of light from the centre to the margins of the projected image (Zeiss, 1931).

Condenser lenses, being always comparatively thick and made of glasses the transparency of which is not perfect, absorb an appreciable fraction of the rays which reach them and thus gradually become heated, sometimes attaining high temperatures with a resultant risk of fracture in case of sudden cooling by a current of air. In spotlights and floodlights, use is made of lenses of stepped (Fresnel) formation (similar to those in lighthouses) which can be very much thinner, and therefore absorb much less light. Such condensers cannot be used in projection and enlarging, as the negative or positive is quite close to the condenser, and the image of the latter would appear in the projected picture.

The usual mounting of condensers, a tube in which the lenses are kept at their normal separation by a cylindrical sleeve and held firm by screwed rings, could very easily be improved. The screw threads are ridiculously fine in regard to their diameter, so that putting together a condenser after cleaning is a veritable feat of patience. Also, while ventilation holes are provided to allow of the expansion of air without interior pressure, they are more or less closed by the sleeve (on the lantern) into which the condenser is fitted, so that they do not allow

the renewal of the air within. Various improvements have been devised in the construction of condensers, but these advances have been applied only recently. For example, segments have been cut out of the lenses permitting the free circulation of air between the glasses and their mount (L. Turillon, 1902); or the screw mount has been replaced by a mount with elastic claws, both permitting the free circulation of air and simplifying the work of taking to pieces and putting together again, as well as the replacement of lenses, in the diameter of which there is always a certain latitude (G. M. Coissac, 1905). Other mountings that facilitate taking apart and putting together for periodic cleaning are those with hinges or with a bayonet joint.

633. Adjusting the Position of the Light. The adjustment of the position of the light must be preceded by the projection of the image to the required size and in rough focus (§ 642). After this preliminary adjustment has been effected, the negative carrier is taken out and the light is centred by examining the illuminated disc in the plane that will be occupied by the sensitive surface.

If the centring is perfect, this disc will be uniformly illuminated. As a rule this will not be the case, faults in centring revealing themselves by characteristic shadows.

If the light source is centred on the optic axis, but is at an incorrect distance from the condenser, the illuminated disc appears bounded by a darker zone which is bluish (light too near the condenser) or reddish (light too far from the condenser). Let us suppose (Fig. 39.2) that the condenser and the lens occupy respectively the positions *C* and *L*, and that the light source *S* is in such a position that its image *S'*, produced by the marginal portions of the condenser, is formed a little in front of the lens. Then all the light transmitted by the condenser will be utilized by the lens, and the latter will produce on the easel a fairly sharp and uniformly illuminated image of the condenser. Let us suppose that, for an enlargement on a smaller scale, the lens is moved farther away from the negative carrier so as to occupy the position *L'*. It is obvious that we shall restore the former condition by bringing the light-source *S* nearer to the condenser *C* until the image *S'* is close to *L'*. If this is not done, i.e. if the light is left too far from the condenser, the marginal parts *O'* of the disc projected on the easel are much less illuminated, being lighted only by the rays least refracted, that is, the red rays.

If the light is not centred on the optic axis common to the condenser and the lens (Fig. 39.3), decentred shadows appear, reddish in the position O_1 or bluish in the position O_2 , according as the lens is in the position L_1 or L_2 , i.e. near the image S_1 of the source produced by the marginal rays, or near the image S_2 of the source formed by the central rays. (In the figure the spherical aberration of the condenser has been greatly exaggerated.)

It may therefore be said that in all cases a

shift of $4\frac{1}{2}$ in. when passing from one position to the other. In order to avoid having to alter the distance of the light afresh for every variation in enlargement, it has been suggested that the negative should be kept constantly in the focal plane of the enlarging lens and to fit the latter with a supplementary lens. A different supplementary lens is used for each different degree of enlargement. If F is the focal length of the lens, it is necessary for an enlargement of n times to employ a convergent supplementary

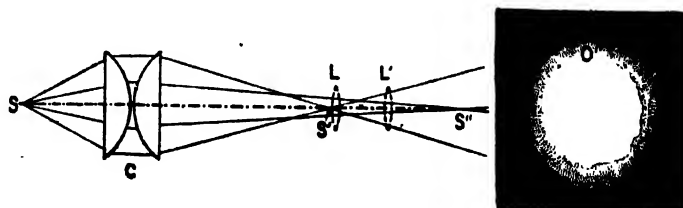


FIG. 39.2. EFFECT OF DISTANCE OF ENLARGING LENS FROM CONDENSER

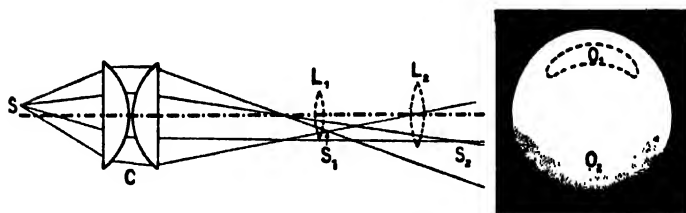


FIG. 39.3. EFFECT OF DECENTRING OF LIGHT-SOURCE FROM OPTICAL AXIS

blue shadow indicates that the light must be moved farther from the condenser, whilst a red shadow is a sign that the light must be brought closer. Finally, any unsymmetrical form of the illumination of the disc shows that it is necessary to shift the light transversely in the direction indicated by the centre of the shadow.

If, for instance, the condenser has a focal length of 5 in. and the negative is at $\frac{1}{2}$ in. from the plane surface (of the condenser) nearest to it, and the degree of enlargement is first 2, and then 10, in each case with a lens of 6 in. focal length (the extra-nodal distances from the negative to the lens being $6\frac{1}{2}$ in. and 9 in., the extra-nodal distances from lens to condenser being about $7\frac{1}{2}$ in. and 10 in., with a condenser of a total thickness of about $1\frac{1}{2}$ in.), then it will be necessary for the light source to be brought to a distance of about $9\frac{1}{2}$ in. and then to about 5 in. from the condenser, that is a

lens of a focal length equal to nF (A. Lockett, 1920).

634. The Choice of a Condenser Enlarger. The usual types of enlargers are described in the catalogues of the principal manufacturers, so that it is only necessary to make a few remarks and to indicate the conditions to be observed in order that the adjustments described in the preceding paragraph shall be possible.

According to the maximum size of the negative to be enlarged, it is preferable to use a condenser of the diameter shown in the table on page 382.

The lens must not be chosen of too short a focal length, especially if it is wished to enlarge on a large scale, for it may be then impossible to project the image of the light source near to the entrance pupil of the lens; insufficient length of the lamp house may make it impossible to move the light far enough back. Besides this, if the light is at a distance from the condenser

Nominal size, in. cm	$2\frac{1}{2} \times 2\frac{1}{2}$ 7 × 7	$3\frac{1}{2} \times 3\frac{1}{2}$ 8 × 8	$2\frac{1}{2} \times 3\frac{1}{2}$ 6.5 × 9	$3\frac{1}{2} \times 4\frac{1}{2}$ 9 × 12	$5\frac{1}{16} \times 7\frac{1}{16}$ 13 × 18	$7\frac{1}{16} \times 9\frac{1}{16}$ 18 × 24	$9\frac{1}{16} \times 12$ 24 × 30
Diagonal, in. cm	4 9.9	$4\frac{1}{2}$ 11.3	$4\frac{1}{2}$ 11.1	6 15	9 22.2	12 30	$15\frac{1}{2}$ 38.4
Diameter of the lenses, in. cm	4 10.3	$4\frac{1}{2}$ 11.5		$6\frac{1}{2}$ 16	9 23	13 32	16 40
Focal length in. approx. cm	3 7.5	$3\frac{1}{2}$ 8		$4\frac{1}{2}$ 11.5	7 17.5	10 24.5	12 30

N.B.—The conversion of centimetres into inches is not absolutely accurate, but is near enough for practical purposes.

more than twice the focal length of the latter, the light-rays converge on leaving the first glass, so that the condenser does not illuminate so large a circle in the plane of the negative which is being enlarged. On the other hand, a lens of too great a focal length renders it necessary to have a room of considerable length (§ 64). In practice it is best to select a lens of which the focal length is at least equal to that of the condenser and does not exceed it by more than 30 per cent.

It should be noted that a lens intended for enlarging by directed light should have an iris diaphragm of metal, as leaves of ebonite may be deformed or burned (§ 72).

The lamp house must be well ventilated, and the ventilation holes must be perfectly light-trapped. The lamp support must be long enough to allow of all the variations that may be required for various degrees of enlargement. A slot should be provided for a sheet of ground glass. This is best placed against the surface of the condenser farthest from the light, and enables the enlarger to be used with diffused light if desired. The position of this ground glass must be far enough from the negative for its structure not to appear in the enlargement.

The negative carrier should slide easily into its slot, but without play. Sometimes the negative stage is movable in relation to the condenser, to which it is then connected by a bellows. This is of value in cases where it is desired to enlarge negatives smaller than the normal size, because they can be placed in a position where the converging beam of light from the condenser is of a smaller section, and thus affords a greater concentration of light. It may be necessary, in order to benefit by this advantage, to replace the usual lens by one of shorter focus. To avoid having to use another lens it has been suggested to use a divergent lens (e.g. plano-concave) between the condenser and the nega-

tive and close to the latter, so as to shift back the smallest section of the beam issuing from the condenser (G. Massiot, 1905).

It is desirable for the negative carrier to be capable of being de-centred, and it is desirable that the enlarger should include no other part capable of being de-centred, at any rate when it is being used with directed light.

ENLARGING WITH DIFFUSED LIGHT

635. Uniform Illumination with Diffused Light. By placing a light source near the focus of a condenser we obtain uniform illumination of a diffuser placed on the other side of the condenser. While this arrangement has been actually used in some enlargers working with diffused light, it is usual to avoid in such cases the expense of a condenser, which can easily be dispensed with.

In the absence of a condenser, means must be taken to ensure the fairly even illumination of the diffuser employed. As a reminder we must mention the use (Schmidt and Haensch, 1913), of the Ulbricht's integrating sphere for uniformly illuminating the negative to be enlarged, commonly used in photometric work. This is a hollow sphere with mat white internal walls in which there is an excentric aperture for the light and an aperture for the negative carrier which is shielded from the direct rays from the lamp.

This system has now been introduced in the U.S.A. (1949) in several models of enlarger which use a circular fluorescent tube (Fig. 39.4). The lamp house takes the form of a flattened hemisphere with the tube slightly above the plane of the negative so that no direct light whatever from the source can fall on the negative. All of the illumination comes from the integrating surface of the hemisphere which is sprayed mat white.

It is, however, more usual to use the light given by an opal lamp together with either ground glass or opal diffusers. This system is scarcely ever completely uniform and it is usually necessary to reduce the excessive transmission in the central part of the diffuser.

To reduce the excess of light in the part of the diffuser directly facing the lamp, it is possible to use a lamp of which the bulb is ground or silvered at the tip. The central area of the diffuser is then lighted only by diffused light. When two diffusers are used, one behind the other, the absorption of light by the centre of the diffuser nearest the lamp may be considerably increased. For instance, in an automatic enlarger made in the United States to the specification of R. S. Hopkins (1918), the first diffuser consists of a sheet of glass of which only the centre is ground, with vignetted edges, while the second diffuser is a glass ground uniformly of fine grain. The same result can be obtained by varnishing or oiling the marginal areas of an ordinary ground glass and by increasing the central absorption by pencilling, or again by placing on a sheet of clear glass cut-outs of tracing paper, or, finally, by using as a mask a negative obtained by exposing a slow plate behind a yellow filter to the light of the lamp, the plate during this exposure being placed in exactly the same position that it will occupy when enlargements are being made. By suitable exposure and development this negative will show a gradation between the centre and edges compensating satisfactorily for the inequalities in illumination.

Whatever the method of illumination employed, it is necessary to see that the diffusers used are of size distinctly greater than that of the largest negative to be enlarged if the marginal areas of the image are to be satisfactorily illuminated, even when enlarging on a relatively large scale, since in this case the extreme beams include the maximum angle of field.

Instead of securing uniform illumination of the diffuser, it is often advantageous to increase slightly the illumination of the marginal portions, so as to compensate for the effect of the obliquity of the extreme beams (§ 56).

636. Combined Lighting Systems. It is common, especially in the case of enlargers for miniature negatives, to use a simple lighting system which consists of a single plano-convex condenser (the flat side of which presses on the top of the negative to hold it flat) in combination with an opal lamp. This system has

the advantages of low cost, no lamp adjustment, and does not show grain and blemishes too badly (advantages which it derives from the diffused light source) and the relatively higher efficiency and shorter exposure of the condenser-enlarger.

637. Vertical Enlargers. The very numerous patterns of vertical enlargers range from commercial models for exact work, built with a rigid frame of cast steel resting on the floor, to the light-weight models for amateurs. In many of the present-day instruments, there is an

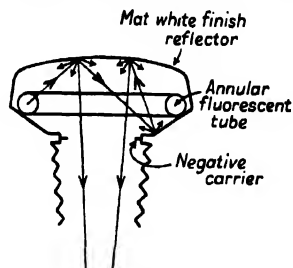


FIG. 39.4. THE LIGHTING SYSTEM OF THE "KODAK FLUORITE" ENLARGER

automatic linkage (§ 69) to keep the negative and the lens in conjugation with the easel. The operator is thus relieved of all attention to focusing, the movement of one part ensuring the correlated movement of the other, so that the image is caused to pass successively through all the possible degrees of enlargement. In the case of directed light, such automatic linkage would be very complicated owing to the need for providing a supplementary link between the light source, condenser, and lens. An additional hand-focusing adjustment (helical lens mount) should be provided. In spite of their obvious advantages the high cost of these fittings prevents their general use.

Owing to the diversity of the types of vertical enlargers, we advise that their detailed descriptions be studied in the leaflets and catalogues issued by the makers.

638. Various Enlargers. From time to time there have been made, for amateur use, attachments interchangeable with the dark slides of a plate camera. These attachments consist of a negative carrier and of a light-box for illumination by diffused light, generally in the form of a mat-white reflector, either plane or parabolic. This is illuminated by one or more lamps placed

on the sides in recesses which shield the negative from direct rays. These enlargers are used like a projection lantern, the image being projected on an easel fixed to the wall.

PRACTICAL ENLARGING

639. Fixing the Sensitive Paper in Position. With vertical enlargers the placing of the paper is usually done by metal *masking frames* which act both as masks with variable openings and as pressure plates, holding the paper flat. Failing these, the paper may be held down by small weights of cast iron or lead placed at the edges and serving also to keep down any mask or strips of opaque paper which may be used to limit the surface to be exposed. The same methods of fixing are applicable to plates or films.

Fixing the paper to a vertical easel by means of drawing pins (steel pins with glass heads forming small grips are preferable to ordinary drawing pins) is practical only if the easel is fixed to the wall or hinged so that it can be turned down into a horizontal position on a rigid support and then returned to the same position that it occupied during focusing. Otherwise there is a risk of shifting the easel when pushing in the drawing pins. A facing of the easel with cork lino partly removes this objection. At various times attempts have been made to construct easels of light metal covered with a layer of pressed granulated cork, but drawing pins do not usually hold if pushed in close to a former hole. If the enlargements are made in only a few sizes, it would be better to use hinged frames which hold the paper stretched by all four sides. It is often preferred to keep the paper flat under a thin sheet of glass in a kind of simplified printing frame, in spite of the fact that the glass sometimes causes a slight diffusion of the light, or a double outline in the images (especially where two very contrasted portions of the pictures meet), even when the glass is without flaws and perfectly clean. It is of service to have squares ruled, or a scale in inches, or rectangles corresponding with the various usual sizes, on the easel, or on the board closing the paper frame (or on a sheet of white card used to cover either when focusing).

Sheets of paper of small or medium sizes are held sufficiently by a *masking frame*, i.e. a frame with a cardboard rebate in which a mask of black paper is placed, and the sensitive paper then kept against the rebate by a flap of card-

board hinged to the frame. This frame is slipped under strips of wood or under the heads of one or two screws partially driven into the enlarging easel.

All these devices may be used for holding films. When enlarging on glass plates it is customary to use a printing frame or a dark slide, either of which is attached to the easel by any convenient means.

640. Testing Parallelism of the Negative and Sensitive Paper. In the case of a vertical enlarger the parallelism of the planes of the negative and easel can be readily tested by means of a spirit level. The instrument is first placed so that the easel is horizontal, and then the light-box is removed and tests are made to see that a glass plate put in the negative carrier remains horizontal in all the positions in which the carrier can be placed.

When using a horizontal enlarger, the parallelism is tested by sights on a mirror successively applied against the negative carrier and the enlarging easel as described in § 162 for adjusting a copying camera.

641. Placing the Negative in Position. Glass negatives are usually held in a frame with rebates with spring turn-buttons to keep them firm. When several negatives of different sizes have to be enlarged one after the other, one may use either a set of adapters nesting one within the other, or separate negative carriers; the latter are better for holding the negative in position.

It is well to cut down to a minimum the amount of stray light due to successive reflections, both in the lens (§ 58) and in any glasses used to hold a film negative. This is done by masking all the superfluous parts of the negative. In this way much cleaner high-lights and margins are obtained in the enlargements.

When a film negative is being enlarged it is usually sandwiched flat between two sheets of glass, which introduces four additional surfaces for stray reflections, and thus tends to veil more or less the enlarged picture, especially in the absence of a mask stopping all light around the part of the negative being enlarged. To prevent heating of the film during exposure from causing shrinkage and warping, it is well to dry it by moderate warming before exposure, and to cover it with a thick glass limiting the amount of heating and ensuring flatness. The number of marks due to dust or to imperfect cleaning are also increased. In the enlarged image there are sometimes annular fringes around each

point of contact of the film with one of the glasses (§ 609). Badly scratched negatives can be much improved, if the number of free surfaces is reduced to two by wetting the film with glycerine and then placing it between the glasses (all air-bubbles being removed), as the whole may be considered as one optical medium; this immersion would, if required, permit the enlargement by "directed" light of films with a mat back surface (§ 243).

In cases where scratched film negatives have often to be enlarged the same result can be obtained more simply by means of a glass trough filled with a volatile fluid which renders unnecessary the washing and drying needed with glycerine. Carbon tetrachloride (a non-inflammable liquid) is generally used; its refractive index is nearly that of the mean refractive index of gelatine, celluloid, and glass (K. C. D. Hickman, 1926). When using a vertical enlarger, a trough with a glass bottom is placed in the negative carrier. This trough contains a small quantity of carbon tetrachloride, and the film is pressed against the bottom by a block of glass with plane surfaces which acts like a paper weight. The lower surface of this block carries a mask of tin foil affixed with gelatine. When using a horizontal enlarger a vertical glass trough with plane-parallel sides is employed; in this the film is pressed against one of the sides by a piece of glass held by wooden wedges. A thread may be passed through two holes on the top edge of the film, so that it can be held at the correct height.

In the customary case of enlargement on bromide paper, so as to obtain a positive image the right way round the emulsion side of the negative must be turned towards the lens; the negative must be turned the other way round if the enlargement is to be used to make a Bromoil transfer (Chapter XLV). It is, of course, assumed that the negative was not reversed when made.

When making enlarged negatives from positive transparencies, the image side of the transparency must be turned towards the lens in all cases where the enlarged negative is to be used for printing that does not involve reversal of the image. But it is the back of the transparency that must face the lens where the negative is required for single-transfer carbon or for printing on the gelatine-coated bichromated paper of the oil process.

642. Focusing the Picture and Bringing it to the Required Size. The work of focusing the

picture and bringing it to the required size is greatly facilitated if the stand of the enlarger is fitted with scales graduated in accordance with trials, supplemented, if need be, by simple calculations (§ 64). Both for focusing and for bringing the image to the right size it is well to replace the negative temporarily by a fogged negative on which inch squares have been ruled with a sharp-pointed stylus, or by a copy negative (same size) of paper ruled in inch squares. The measurement of the squares on the easel (which may be done by squares ruled on the easel) greatly simplifies the estimation of the degree of enlargement, and sharpness is often easier to gauge in the image of a fine cut in an opaque layer than in an image with a more or less definite outline.

Those with a fondness for mathematical calculation can work out the distance to move the negative in relation to the easel, or vice versa, in order to obtain an enlargement of given size. After focusing accurately without regard to the size, measure on the easel the length L' occupied by an object which on the negative has a length l and which is required to have a length L in the enlargement. In order to change the adjustment at this setting to that required, it is necessary to increase (if L' is smaller than L) or to reduce (if L' is greater than L) the distance from the negative to the easel by the length

$$\left[\frac{L' - L}{l} - l \left(\frac{1}{L'} - \frac{1}{L} \right) \right] F$$

where F is the focal length of the enlarger lens, then re-focus the lens until sharpness is again attained.

As the operator intercepts the projected image if he tries to approach the easel to examine the sharpness of a detail, there have been placed on the market accessories comprising a base for application on the paper, a sloping mirror and an eyepiece so fixed that it is sharply focused on the plane on which the base rests. The image is therefore sharp on the easel when it appears sharp through the eyepiece (A. von Lagorio, 1931).

When a new lens is being used for the first time, it is well to see that the sharp visual image coincides with the sharp photographic image. For this purpose the ruled focusing plate is enlarged on to a strip of paper arranged obliquely, e.g. at a slope of 1:10 to the easel. A pencil mark is made on the line which appears sharpest, and after development the line which is sharpest

is picked out and the distance between it and the mark is measured; the displacement of the plane of sharpness will then be $\frac{1}{n}$ of the distance measured.

In choosing the scale of enlargement, remember that portrait enlargements termed "natural size" must always be slightly smaller than in nature, otherwise they will appear much too large under the usual viewing conditions.

If the dimensions of the apparatus or of the room do not permit of the required enlargement being obtained with the usual lens, one of shorter focal length may be substituted, or the usual lens may be fitted with a supplementary converging lens (§ 117), so as to form a system of focal length shorter than that of the usual lens. The focusing will then have to be checked by the method described above. The aberrations introduced by such a supplementary lens frequently have the effect of reducing sharpness.

Enlarging may also be done in stages, first making an enlarged transparency and then, from it, a negative enlarged to the required scale.

643. Soft-focus Enlargements. The various methods for producing images of "soft focus" (§§ 331-2) are applicable to enlarging, but it must be noted that the afocal supplementary lenses mentioned in § 126 can be used only with diffused light; in the case of enlargement with directed light their effect would vary with beams of various degrees of obliquity.

One of the most commonly employed methods for modifying excessive sharpness of enlarged images consists in placing between the lens and the sensitive paper a piece of bolting silk, canvas, bolting cloth, or muslin (all preferably black). When such a fabric, stretched on a wooden frame or on a sheet of glass, is laid against the sensitive paper, it simply reduces the contrasts of the image (E. H. Farmer, 1905), giving it a pattern which, as a rule, is not objectionable. As the fabric is gradually removed from the plane of the sharp image an increased degree of diffusion is imparted to the image. It is even possible to stretch one or more thicknesses of black chiffon on a lens hood, securing them by a rubber band. If the fabric is used at a considerable distance from the sensitive paper, it is necessary to place it in position before focusing, and to allow for its effect in prolonging exposure.

644. Ascertaining the Exposure. When the enlargement is made with diffused light, and in this case only, the trials for finding the correct exposure may be made with a very small strip of paper exposed in contact with the negative

to be enlarged in a printing frame placed in the same position as the large sheet of paper will be placed for enlargement. This test must, of course, be made only after the various adjustments have been carried out.

It is the usual practice to find the correct exposure by a test strip of paper placed on the easel and illuminated by the enlarged image in the same conditions under which the final print will be made.

When the exposures best suited for the contact printing of two negatives of very different densities on identical sensitive papers are known, all operations being carried out under the same conditions, then the proportion of these two exposures will hold good in the case of enlargements of the same magnification in diffused light and under identical conditions (same light, same paper, same development).

The optimum exposure can also be ascertained, in the actual conditions of enlarging, by measuring the illumination of the shadows of the projected image with a photo-electric exposure meter, provided that these instruments are calibrated by methodical trials for this special purpose.

There are two meters commercially available in Britain for the simple calculation of exposure in enlarging. Both are instruments employing the principle of the Bunsen grease-spot photometer, but they vary slightly in the method of varying the standard light source against which specific portions of the enlarged image are compared. The pattern which varies the intensity of the standard by distance from the grease-spot would seem to be fundamentally more sound than that employing a variable resistance.

645. Control During Exposure. In all cases where the image is projected on to sensitive paper exposed uncovered in the darkroom, it is easy to modify the tones of the various parts of the image (particularly when a long exposure is given) by masking the parts to be lightened for a suitable fraction of the exposure. The mask used must always be held fairly well away from the sensitive paper, so as to project on it only a soft-edged outline, and it must be kept in constant movement to soften the edges of the cast shadow still further.

For instance, to bring out the gradation of the sky in a landscape negative, a piece of card is used, cut either with a straight edge or according to the outline pencilled on it (before the sensitive paper has been placed on the easel)

while it is held about half-way between the lens and the sensitive paper. This card is moved, during part of the exposure, to and fro or up and down.

To lighten the face of a model dressed in white, or any other part surrounded by areas of which the exposure requires to be longer, a piece of black paper or thin card, cut to the suitable outline, is fixed by means of a strip of gummed paper to a loop of thin wire extended so as to form a handle, and is held during part of the exposure so as to shield the part to be lightened. If the wire is sufficiently thin and is held far enough from the sensitive paper, no trace of the handle will appear in the image.

Finally, to darken a portion of the image completely surrounded by areas of which the exposure has to be lessened, a card is used of size large enough to cover the whole of the sensitive paper and in which an aperture of suitable shape has been cut.

646. Excessive contrast in an image can be weakened during enlargement by the following method (O. Mente, 1910). Before putting the paper on the easel (which latter may be covered with a waterproof fabric) the paper is soaked in a developer, without tendency to give either aerial fog or coloured products of oxidation (a solution of glycine with a little sulphite is well suited for this purpose) and thickened by adding some glycerine, glucose, or sugar. After a very short exposure, serving to print only the deepest shadows, the lens is covered with its orange cap and the shadows are allowed to develop. The silver deposit thus obtained very effectively protects the underlying emulsion against the action of light during the final exposure. From time to time a sponge, dipped in the developer and then squeezed, is passed over the surface of the enlargement. According to the effect desired, the exposure may be divided into a variable number of periods, allowing the developer on each occasion the necessary time to develop the exposed silver bromide. It must be borne in mind that the sensitivity of the paper is lowered by wetting with the developer. Owing to the rather long time taken for complete development it is necessary to choose a paper without tendency to fog or stain yellow during prolonged development.

647. A very ingenious method for indirectly retouching enlargements has been suggested by C. Duvivier (1924), who got the idea from a method of drawing from a photograph previously described by L. Misonne. A sheet of white

paper is fixed on the easel and a sheet of translucent paper is placed over it in such a manner that a sheet of sensitive paper may be slipped between them without shifting the tracing paper. Using the projected image as a guide, the tracing paper is covered with pencil work or black chalk worked with the stump in all those areas requiring lightening or masking. After completing this retouching, the sensitive paper is inserted and the exposure is made, the normal exposure being increased to compensate for the absorption of some of the light by the tracing paper. This method is particularly advantageous when several enlargements have to be made from one negative, part of the retouching being thus done once for all.

To carry out this method, called by its author "the extreme limit," the enlarged image of a negative is projected on to a sheet of drawing paper in the darkroom. It may then be worked over with pencil or charcoal, so that this added drawing and the projected image together form a uniform dark grey. This, however, would give a servile copy of the image; it is easy during the work (in which placing is assured photographically) to carry out any modification or simplification dictated by the artistic ideas of the draughtsman.

648. Compression of the Middle Tones in Enlargement from Negatives of Excessive Contrast. Besides the Person process, §730, which is particularly suitable for enlarging, two working methods may be outlined which need not be confined to enlarging. For example, if the correct exposure time for the shadows is 40 sec, and 10 sec for the high-lights, an exposure is given equal to $40 - 10 = 30$ sec through a screen of about 40 lines per cm which is held against the paper by means of a sheet of glass. The screen is removed, but not the glass (to avoid any change in the focal setting) and a 10-sec exposure is given. On the paper, therefore there are two images one being correct for the high-lights (elementary areas protected during the first exposure) whilst the other is correct for the shadows. The best effect is obtained when the opaque elements of the screen cover half its area (W. Anderan, 1939). Similar results may be obtained if the screen is replaced by a piece of fabric having loose opaque threads.

649. Handling of Enlargements of Large Size. When making enlargements of size greater than that of the largest dishes available, it is practicable to fold the sheet in two if its smaller side does not exceed the longer side of the dish.

Otherwise, the print may be laid horizontally on a boarded or tiled floor, or hung up vertically and covered with developer by means of a brush of soft hairs or by means of a hand atomizer as used by florists. In any case, the print must first be wetted with clean water so as to facilitate the uniform spreading of the developer, and the developing solution must be one of those without tendency to aerial fog or yellow stain (glycin

solution with little sulphite). If the print is hung vertically, the developer must be thickened with glycerine, glucose, or sugar. Development must be stopped with an acid bath, and fixing must be prolonged so as to ensure the solution of all the silver salts. Washing is best done with a stream of water directed alternately to one side and the other. (See §§ 697-707 for methods of developing paper prints.)

CHAPTER XL

SILVER PRINT-OUT PAPERS

650. General. Print-out papers, which were about the only silver salt papers in use towards the end of the nineteenth century, are now only used occasionally and, consequently, only the most important data will be given in this chapter. A more complete description can be found in an earlier edition. We shall consider here chiefly those papers in which the sensitive material is silver chloride associated with an excess of soluble silver salts (nitrate, and organic salts, such as citrate, tartrate, etc.).

Depending on the strength of the light by which the printing is carried out, the colour of the image varies from blue-violet (the colour of image given by pure silver chloride), to red (the colour of image given by most of the salts accompanying the silver chloride; these salts are less sensitive, and so require a very strong light). The degree of humidity of the film considerably affects the colour of the image. A damp condition increases the sensitivity of the accompanying salts without affecting that of the chloride, and so, for a given exposure, the image is redder than that given by a dry film.

With these print-out papers the image consists of silver in a very fine state of sub-division (colloidal silver), absorbed (solid solution) in the excess of silver chloride, and thus protected against certain reagents which attack metallic silver. This solid solution of metallic silver in silver chloride has for long been considered as a definite salt, the sub-chloride of silver to which was assigned the probable formula Ag_2Cl . It is now definitely established that silver sub-chloride does not exist and that the mixture (sometimes called the photo-chloride) can be obtained by coagulating a mixture of colloidal solutions of silver and silver chloride (Lüppo-Cramer, 1910). The amount of silver per unit area of a very intense black is extremely small. An albumen paper which, before treatment, has an amount of silver salts equivalent to 0.68 g of silver per square foot has only 0.09 g per sq ft after treatment (Haddon and Grundy, 1895). This amount of silver, if in the condition of metallic leaf of the same area (the thinnest beaten leaves that can be obtained are much thicker), would be 0.07μ thick and almost completely transparent.

The image is generally more contrasty when it has been printed by weak light than when strong light has been used (see § 608, effect of coloured light). It is interesting to note the possibility of increasing the contrast of an image printed on print-out paper by placing between the negative and the printing paper a yellow or red filter which is easily bleached by light and which, therefore, after a certain amount of exposure, becomes a sort of duplicate of the negative. A film impregnated with ferric thiocyanate may be used (G. Staess, 1917).

If the exposure to light is prolonged sufficiently to saturate the remaining silver chloride, the silver which is liberated may appear on the upper surface of the film in a coherent state with a greenish metallic lustre; the image is then said to be *bronzed* or *metallized*.

Fixation of prints obtained by direct darkening causes a general weakening of the image which is chiefly visible in the lightest tones. This effect varies with the type of paper and also, though to a smaller extent, according to the conditions of printing (colour and intensity of the light). This *regression* of the image makes it necessary in all cases to continue the exposure until a darker image than is required is obtained; a few preliminary trials will show the depth of printing required for retention of the finest details in the high lights.

During fixation the image becomes yellow in colour and after washing and drying acquires a disagreeable yellowish-brown colour. The yellowing of the silver photo-chloride in the fixing baths is due to the transformation of the "colloidal silver—silver chloride" system into a new "colloidal silver—gelatine" system of much lower refractive power, so that the maximum of absorption is displaced towards the short wavelengths (M. Savostjanowa, 1935). In drying, the tone darkens somewhat, the refractive power of the dry gelatine being slightly higher than that of gelatine swollen with water. The yellowing is remedied by toning the image (before, during, or after fixing), that is to say, by substituting another metal (gold, platinum, etc.) for a portion of the silver, or by converting the silver into a coloured compound (e.g. selenium toning).

A very faint image on a print-out paper can be brought to a normal depth either by depositing silver on it by physical development (which, in this case, can be regarded as an intensification process), or by exposing the paper to an orange or red light.

651. The sensitive layer of print-out paper in the initial state, is not affected by yellow or red light even on prolonged exposure, as the limit of spectral sensitivity is 520 m μ . When, however, a feeble image has been imprinted by white light, it is reinforced by uniform exposure to red light. This phenomenon was noticed in Daguerreotype images by E. Becquerel in 1840 who gave to these yellow and red radiations the name "continuing radiations." The effect was explained by Lüppe-Cramer (1909) as being due to a panchromatic sensitization of the silver chloride by the photo-chlorides formed. It is of particular importance if soft prints are required from very vigorous negatives; in this case exposure under the negative should be carried just far enough to obtain full detail in the shadows.

The continuing action of yellow or red light can be used for increasing the contrast of an image which has been made from a negative with weak contrast, but in this case the second exposure should be made through the negative in order to graduate the intensification of the image (H. J. Channon, 1909).

652. **Deterioration of Print-out Papers.** The ageing of print-out papers containing soluble silver salts is shown by the appearance of a yellow colour, due to the spontaneous reduction of minute quantities of silver in a very fine state of sub-division. The yellow colour changes to brown and finally to black with a metallic lustre. This change does not occur in complete absence of moisture, and so these papers are generally packed in waterproof paper after having been dried and stacked face to face with each adjacent pair separated by a sheet of straw paper which acts as a desiccating agent. The deterioration of print-out papers is very rapid when they are exposed to the action of certain gases and vapours (hydrogen sulphide, formaldehyde, hydrogen peroxide formed during the oxidation of resins, etc.) which, as already indicated, give fog with gelatine silver-bromide emulsions.

These papers should be kept in a dry place, away from any chemical operations. These recommendations are particularly important in the case of opened packets.

If the coloration of the paper by age is not very pronounced, it disappears in the course of somewhat longer fixing, unless the fog has been "consolidated" by toning before fixing.

SALTED PAPER AND ALBUMEN PAPER

653. **Salted Paper.** Salted papers are sized with starch paste containing a suitable quantity of chlorides and other soluble salts, which are sensitized after drying by floating on a solution of silver nitrate and again drying (de Brébisson, 1854). The starch paste may be replaced by other sizes, such as resin soaps in aqueous or alcoholic solutions, agar-agar, etc. A more rapid paper can be obtained by using alkaline phosphate instead of chloride. The keeping qualities of this paper are very limited, and it is suitable in general only for very vigorous negatives, but by the addition of small quantities of potassium dichromate the contrast of the images can be increased, thus making it possible to use average or weak negatives. It is no longer a general article of commerce. The absence of any coating, other than the normal sizing of a good quality drawing paper, makes it possible to draw on the paper with pen or pencil; the photograph can thus be used as a guide and then caused to disappear when the drawing is nearly finished. Such prints should be fixed, not toned. Photographs on salted paper can also be worked up with water-colours; the image is faintly printed and toned to a neutral colour, which gives the outlines and gradation in the shadows.

The preparation of salted paper is one of the easiest of operations, but owing to its bad keeping qualities it can be sensitized only in small quantities at a time.

654. **Preparation of Salted Paper.** Paper of good quality, suitable for water-colour painting, is first of all marked with pencil on the back to avoid subsequent confusion, and then pinned to a small clean board or stretched out on a drawing board. The salted size is then applied with a thin flat brush with cross-brushing. If the paper is of pronounced texture it is necessary to brush the size well into the cavities. Finally the coating is treated with a soft badger brush until it appears to be uniformly mat.

The size is best made with *arrowroot* (a starch chiefly used as a food-stuff). The amount required can be calculated on the basis of about 60 ml per sq ft, but allowance must be made for loss in working.

Grind about 35 g of arrowroot in a mortar

with a small quantity of water, until a thick paste free from lumps is obtained. Dissolve separately 3 g of citric acid and 35 g of sodium chloride (table salt) in 950 ml of water. This solution is brought to the boil in an earthenware vessel, and the arrowroot cream is then added in small quantities with constant stirring with a stirrer or wooden spoon. Boiling is continued for a few minutes, and the mixture is left to cool; after cooling, the surface skin is removed.

As paper thus coated has rather better keeping qualities, a large quantity may be prepared for sensitizing when required.

655. Sensitizing must be done in the absence of white light; it is convenient to work at night by artificial light. The drying must be done in darkness.

The sensitizing bath is prepared by mixing—

Silver nitrate (cryst) ¹	. . . . . 100 g
Citric acid ²	. . . . . 75 g
Alcohol (90 per cent)	. . . . . 75 ml
Water, distilled, to make	. . . . . 1000 ml

Dissolve each solid separately in a part of the water, mix and then add the alcohol.

The solution is poured into a perfectly clean glass dish and should be about $\frac{1}{4}$ in. deep. The salted paper is floated on the surface of the bath face downwards by lowering it gradually; it is then removed to make sure that it is uniformly wetted and re-floated with the same precautions. After about five minutes the sheet is lifted by one corner and withdrawn from the dish; by drawing over a glass rod, most of the adhering solution is removed. The paper is allowed to drain for a few seconds and is then put to dry in the dark. The clips used for hanging the paper from the drying line should have been previously soaked in melted paraffin

¹ Silver nitrate (M.Wt. = 170) is supplied either in the form of colourless crystals or as cast white or grey masses (lunar caustic); its density is 4.35. It is very soluble in water (more than 60 per cent at 32°F), and slightly soluble in strong alcohol. The crystals and solution are stable. Silver nitrate deposits black stains of metallic silver on the skin or on other organic matter (cloth, wood, etc.) when acted on by light. These stains may be removed by successive treatments with tincture of iodine (or iodine dissolved in potassium iodide) and strong solution of sodium thiosulphate.

² Citric acid is extracted from the juice of the lemon or prepared by fermentation ($\text{COOH} \cdot \text{CH}_2 \cdot \text{C}(\text{OH})\text{COOH}$, $\text{CH}_3 \cdot \text{COOH}$ —M.Wt. = 210). It is formed in colourless crystals very soluble in water (greater than 60 per cent at 15°C). The crystals are stable but mould rapidly develops in solution. Commercial samples may contain traces of lead and arsenic. It is sometimes adulterated by tartaric acid which has similar photographic properties.

to render them impermeable. Drippings from the papers should be caught by any waste paper available, the ashes being afterwards added to the silver residues. The dry paper should be packed and kept in a dry place.

The *silver bath* may be used repeatedly; in proportion to its use, it becomes poor in silver and rich in sodium nitrate; the presence of this latter salt makes the readings of a Baumé hydrometer, which is sometimes used for estimating the concentration, entirely misleading.

A used bath can be frequently revived by the addition of fresh solution of somewhat greater strength, but after a time it is necessary to discard it and to recover the silver. Silver is recovered by the addition of sodium carbonate, which precipitates the silver as silver carbonate. This can be converted into silver nitrate by adding nitric acid and evaporating. If one does not carry out the recovery oneself, the old silver bath is best added to used fixing baths, to avoid increasing the number of operations.

656. *Use of Salted Papers.* Prints on salted papers which are intended only to act as guides for drawing are simply fixed; after the drawing is finished the image is destroyed by immersion in one of the subtractive reducing solutions previously mentioned (§§ 555–8). The paper is then washed and dried.

In all other cases the image usually has to be toned. While toning can be done after fixing, it is quicker and gives more regular results if done before fixation.

Gold toning is best done in an alkaline bath, and notably by "chalk toning" (§ 664); black tones can be obtained by toning with platinum (§ 668) after previous partial toning with gold.

Economy of the toning bath can be effected by washing the prints in several changes of water before toning; a preliminary treatment in a chloride solution, recommended below for emulsion-coated papers, considerably slows the toning of prints in a gold toning solution which contains no solvent of silver chloride.

Fixing should be in an alkaline solution and should be followed by washing in plenty of water.

657. *Albumenized Papers.* From 1850 until 1890 almost all photographic printing was done on albumenized paper (Blanquart-Evrard, 1847). Smooth paper was floated on the surface of a solution of albumen (white of egg) containing sodium chloride and citric acid. The paper was supplied ready for sensitizing, in the manner

already described for salted paper (§ 654), or ready for use. The introduction of emulsion-coated print-out papers caused the gradual disappearance of albumenized paper, as commonly used.

Meanwhile papers sized with vegetable albumen, with casein and with other colloids, appeared under the name of *mal-albumen paper*, and were used chiefly by professional portrait photographers. These papers require negatives which are much less vigorous than those for printing on to the older type of albumen paper, and softer still than those for salted paper. They were usually prepared by coating a sensitive emulsion on to the paper, and the method of use is, therefore, similar to that recommended for emulsion-coated print-out papers. But the sensitive film is much less coherent, and all rubbing should be avoided, particularly when the prints are wet.

658. Sensitizing Silk. The working methods for sensitizing silk fabrics do not differ from those employed in the preparation of salted paper, except in the choice of a sizing material. This latter must be removed in the course of the various operations in such a way that the normal appearance of the fabric shall be preserved. A mucilage of lichen (moss) is usually prepared for this purpose in the following manner.

Infuse 45 gr (5 g) of Iceland moss (pharmacist's moss) in about 20 oz (1,000 cc) of boiling water; decant and filter the solution (which should be of a thin, syrupy consistency) while hot. In 18 oz (900 cc) of the filtered solution dissolve 350 gr (40 g) of sodium chloride (kitchen salt) and add 2 oz (100 cc) of glacial acetic acid to keep down all fermentation of the infusion. Keep the mucilage in a corked bottle.

Pour the solution into a perfectly clean dish and float the pieces of silk (which should have been previously marked on the back with pencil) on the solution, taking care to remove air bubbles and to prevent the liquid reaching the back of the material. This is done by taking the material by two opposite corners and allowing the tip of the loop to touch the liquid first; the corners are then lowered gradually until the whole is touching the liquid. After about two minutes the material is removed from the bath by taking hold of two adjacent corners; it is dried by pinning to a stretched cord.

The pieces of material, which should be thoroughly dry and free from any smell of acetic acid, are then floated for about two

minutes on the silver bath already described for salted papers (§ 655), drained, and dried.

As the image on silk is more or less buried in the fibres, the contrasts suffer, so that a vigorous negative is called for, particularly with material with a pronounced grain. The negatives used should be varnished as a protection against small crystals of silver nitrate which become detached from the surface of the silk.

After printing, with the precautions specified in § 656, it is advisable to fix the tissue provisionally to a pliable card. Toning follows and then fixing in the manner described for salted paper. After washing and drying, the tissue should be smoothed with a hot iron. Such tissue can be cleaned when need arises by the methods which would be used for the plain material itself.

GELATINE AND COLLODION P.O.P.

659. Print-out Silver Emulsions. The contraction P.O.P., used in England for emulsion print-out paper, originated with the Ilford Co., on their taking up the first manufacture of this type of paper in England. On the Continent, the term "aristotype" is still used to denote the gelatine variety, as distinguished from the collodion, of print-out paper. Print-out emulsions are made on the commercial scale by the precipitation in gelatine (gelatine P.O.P. Abney, 1882) or in collodion (collodion papers, G. Wharton-Simpson, 1865) of silver chloride (or sometimes silver bromide or phosphate), together with silver citrate, tartrate, or oxalate. The unwashed emulsion contains an excess of silver nitrate in addition to the salts resulting from the double decomposition (nitrates of potassium, lithium, strontium, etc.).

These emulsions are coated mechanically on to baryta-coated paper. The paper for print-out emulsions is made chiefly from rags (clippings from lingerie and sail-making workrooms, and old rags that have been cleaned and sorted out).

Collodion paper—and, still more so, the gelatine paper—require negatives much less vigorous than those required for salted paper. Certain varieties of collodion paper have been prepared (F. Hedliczka, 1904) with emulsions containing silver chromate (the film is yellow or orange, according to the quantity of chromate present), for medium or weak negatives (*contrasty papers*).

Collodion papers give a much richer image and are more suitable for warm, black tones by successive tonings with gold and platinum. In

warm climates these papers have the advantage that they can withstand baths and washing waters at a temperature which would probably cause the coating of the gelatine P.O.P. to soften somewhat.

The castor oil, which is often added to collodion emulsions to give suppleness and to avoid risk of cracking, is sometimes a cause of trouble through being present in excess; in these circumstances it is difficult to make the various baths wet the surface of the film. The same trouble sometimes arises when glycerine has been used to give suppleness, if the glycerine has, in the course of time, soaked out into the paper support. Immersion in denatured alcohol before attempting treatment in any of the baths will make the film penetrable to the solutions (J. Gaedicke, 1911) or alternatively, a wetting agent may be used in the baths.

660. Use of Collodion and Gelatine P.O.P. These papers are either toned prior to fixing or toned and fixed simultaneously in one bath (§ 671). For separate gold toning the alkaline baths recommended for salted and albumen papers can be used for gelatine papers, although their actions are very slow. But they are almost without action on collodion papers; these latter should be toned in a bath containing a solvent of silver chloride, e.g. sulphocyanide or thiocarbamide which can gradually make a way through the slightly permeable film of collodion. Collodion papers (and particularly the glossy varieties) curl to a roll in the first bath into which they are placed.

This can be avoided as follows. Place the prints face downwards into a dish containing a very small amount of liquid and spread them irregularly over the bottom of the dish in such a way that they are in contact with each other. Almost all the liquid should have been absorbed by the time that the last print to be treated has been put in. Let the liquid drain away by squeezing the pile of papers against the bottom of the dish. After 5 or 10 min the prints will be flat, and it will be possible to proceed with washing; in cold weather, warm the water slightly.

As in the cases of the papers already considered, an economy in the toning solution can be effected by preliminary washing; or, if it is intended to recover the silver residues, the soluble salts can be held in the film until fixation by treating with a bath of salt followed by careful washing.

Fixing, when carried out separately, is best done in an alkaline bath.

These papers are also used for proofs to permit clients to choose a preferred pose, etc. Such prints, usually not fixed or toned, are made without any regard being paid to the loss of depth which would occur on fixing; they cannot usefully be toned or fixed. In some cases they bear a rubber-stamp impression (made with a colourless, greasy varnish), or may even be coated with paraffin wax rendering any treatment very difficult. Some studios do fix and tone their proofs but in such a manner that their destruction is ensured after a short time.

661. Print-out Papers from Old or Fogged Development Papers. Gelatine-bromide or gelatine-chloride development papers, which, for one reason or another, have become unsuitable for their proper purpose, may be converted into print-out papers by soaking them in a weak solution of silver nitrate (about 0.5 per cent) or in a solution of a reducing substance such as sodium or potassium nitrite (about 5 per cent), salts of hydrazine, various developers, sodium sulphite, stannous chloride, etc.

After soaking for some minutes, the paper is placed to dry in the dark without any preliminary washing. The same treatment can be applied to negative plates and films.

The method of using is the same as for gelatine print-out papers.

MANIPULATION OF PRINT-OUT PAPERS

662. The Printing-room. The loading of the printing frames, the control of the exposure, and the unloading of the frames should be done in a room lighted by artificial light or subdued daylight. Normal daylight may be used with a yellow window.

On the commercial scale, one side of the printing-room was usually lighted by yellow windows and the other by plain glazing; the dry paper could then be handled and the first operations done by yellow light, whilst other treatments, from fixation onwards, could be carried out in white light. When it was necessary to work by artificial light, the ordinary lamps were used; for judging toning, a lamp with a blue glass bulb, giving a light similar to daylight, was preferred in order that the tone could be more exactly judged.

For print-out papers the methods of washing and drying were exactly the same as for the present-day development papers.

663. Gold Toning in Alkaline Baths. The immersion of a photographic print in a solution

of pure gold chloride¹ would result in the substitution of gold for some of the silver constituting the image, but the resulting image would be very weak, particularly in the lighter tones. This weakness does not occur with solutions feebly acid (pH 4.5) where the yellow auric salt has been converted into the colourless aurous salt which, when replacing the silver of the image, deposits three times as much gold per unit amount of silver as the auric salt. Now, in an alkaline medium, auric compounds change progressively into aurous compounds; these, however, may pass over into the inactive aurite state in the absence of soluble chlorides or if the bath is too alkaline.

The colour of the toned image depends essentially on the speed of the toning, which, in its turn, depends on the alkalinity of the bath. An acid bath gives images which tend to be red (finely divided gold), while a bath which is alkaline results in images which tend to a purplish brown, which may even approach black (gold in a less finely divided condition). Toning baths of a moderate temperature should be used. A bath which is either too hot or too cold does not give such good tones as one which is at a temperature round about 65°F.

664. Toning baths can be made alkaline by using one of a number of salts which have a feebly alkaline reaction; fused sodium acetate,²

¹ The gold chloride of commerce is actually chlorauric acid ($\text{HAuCl}_4 \cdot 3\text{H}_2\text{O}$ —M.Wt. = 394), and occurs in the form of yellow deliquescent masses (sometimes coloured brown by the addition of small quantities of iridium salts to satisfy a demand arising from the belief that the brown-coloured gold chloride is better than the yellow), very soluble in water, alcohol, and ether. The best qualities contain 50 per cent of gold, but unfortunately products having a much smaller gold content are sold (gold chlorides exist which have a gold content varying from 50 per cent to 20 per cent in 5 per cent stages) without any indication of the difference in quality, and without there being a difference in price commensurate with the amount of active material present. The chloraurates of sodium and potassium ($\text{KAuCl}_4 \cdot 2\text{H}_2\text{O}$ —M.Wt. = 414, and $\text{NaAuCl}_4 \cdot 2\text{H}_2\text{O}$ —M.Wt. = 398), which are deliquescent and of which the gold content rarely exceeds 40 per cent, are also prepared commercially under the description of double salts of gold and potassium or sodium. The aqueous solutions of these various salts are quite stable if they are not in contact with organic matter; they should be prepared with distilled water and should be kept in ground-stoppered bottles and stored in the dark as they are slowly reduced by light.

² Fused sodium acetate (CH_3COONa) occurs in white or grey fibrous masses, which give a neutral or feebly alkaline solution, while crystalline sodium acetate (colourless crystals) usually contains a certain amount of free acetic acid.

borax, disodium hydrogen phosphate, etc., may be used. These salts give the same results when they are employed in quantity sufficient for the bath to be equally alkaline in each case. The following solution, for example, may be used—

Sodium acetate, fused . . .	10 g
Borax . . .	1.0 g
Gold chloride (1% solution) . .	.25 ml
Water to make . . .	1000 ml

The solution may be used after standing for about one hour. The used bath can be kept, but it is necessary to add small quantities of gold chloride from time to time.

The most definite means of ensuring the constancy of the composition of the bath is to use *chalk toning* (H. de Molard, 1851); the insoluble calcium carbonate is kept in the bath and does not react except as required. The following method of working is recommended (E. Lamy, 1897).

First of all, the following mixture is prepared with shaking.

INACTIVE BATH

Whitening (powder) . . .	5.0 g
Gold chloride (1% solution) . .	50 ml
Warm water (about 100°F), to make	1000 ml

The bath will become colourless on cooling; it should not be filtered. When required for use, decant the necessary volume of this liquid, and for each 100 volumes of the inactive bath add two volumes of 1 per cent gold chloride solution. When the toning is seen to be slowing down, more gold chloride should be added. The used bath is replaced in the inactive-bath stock-bottle and shaken up with the chalk.

The washed prints are placed one by one into this bath, and pass from an initial red-brown through dark brown and purplish-black to purplish-brown. Toning may be stopped at any stage, and after fixing, washing and drying, the print will be red-brown, warm black, or pure black; slight variations will occur from one paper to another. As the prints reach the desired tone they should be removed one by one and placed in water, where they may be left until sufficient have accumulated for fixing.

665. Sulphocyanide Toning. If a solution of a thiocyanate¹ (sulphocyanide) is added

¹ The sulphocyanides of ammonium and potassium (NH_4CNS —M.Wt. = 76 and KCNS —M.Wt. = 97) occur as small colourless deliquescent crystals, very soluble in water and alcohol; the dry salts should be kept in hermetically sealed bottles; the solutions keep fairly well. In the preparation of toning solutions ammonium thiocyanate is generally preferred. Concentrated aqueous solutions dissolve gelatine.

progressively to a solution of a gold salt, the red precipitate of auric sulphocyanide which is at first formed re-dissolves in the excess of sulphocyanide to give the complex colourless sulphocyanide. This double salt slowly (or rapidly under the influence of heat) changes into aurous sulphocyanide.

These solutions can be used for toning print-out papers (Meynier, 1863). Tones which are almost black can be obtained by replacing the sulphocyanide by thiocarbamide or thiourea¹ (A. Hélain, 1902).

As these compounds are solvents of silver chloride, a fresh toning bath attacks the silver chloride image to some extent, causing very rapid toning. In addition, the finished image may have a very much greater proportion of gold in it than it would have had if it had been toned in an alkaline bath; these properties are obviously not to be found in an old bath saturated with silver chloride. F. Novak (1902) has found the following gold-silver ratios for images which have been thoroughly toned—

Albumen paper toned in a bath made alkaline with borax	1 : 4.3
Collodion paper toned with gold sulphocyanide	1 : 0.25
	to 1 : 0.85
Collodion paper toned and fixed simultaneously in a new bath	1 : 1.14
	to 1 : 2.00

It seems well established, however (R. E. Blake Smith, 1913), that the toning is not due exclusively to the gilding of the image, but that a small portion at least is due to sulphuration during the fixing, which follows the toning; the tone is modified considerably in the process of fixation after the solution of the silver chloride is complete, and the image becomes first a yellow-brown, and then slowly changes to purple. A more exact idea of the tone of an image can be obtained by examining it by transmitted light.

666. As the sulphocyanide toning bath is very readily exhausted, and as its action is very rapid even when the solution is weak, the best method of working is to use only the amount of chemicals corresponding exactly with the treatment of a given number of prints, according to the method recommended in 1900 by the

Eastman Kodak Co., for gelatine P.O.P. This also applies to all other print-out silver-salt papers.

Prepare two stock solutions—

A. Gold chloride	2 g
Water to make	1000 ml
B. Ammonium sulphocyanide	20 g
Water to make	1000 ml

and according to the number of prints to be toned, and having regard to the colour required, take of each solution A and B—

FOR 12 PRINTS 7 × 5 in. (13 × 18 cm)			
Purplish-black	Purplish-brown	Sepia brown	Deep sepia
100 ml	75 ml	60 ml	30 ml

Add water in sufficient quantity for it to be possible to tone all the prints together. For 12 prints 7 × 5 in. the total volume should be about 500 ml, e.g. the toning bath for purplish-brown is: A, 100 ml; B, 100 ml; water, 300 ml. The bath thus mixed is ready to be used after it has stood for two hours.

The washed prints are placed in the bath one by one, and are kept constantly in movement during the whole time of toning to avoid their sticking together. According to the nature of the paper, the depth of the prints, and the dilution of the bath, the time of toning will vary between 5 and 15 minutes.

Very varied colours may be obtained with gelatine print-out papers (but not with collodion paper) by adding small quantities of potassium iodide to the toning bath (A. Hélain, 1901). The weight of iodide must not exceed six times the weight of gold chloride used. This maximum quantity gives carmine tones; reddish tones are obtained by using less iodide. The general yellow colour of the coating, which is caused by the conversion of a portion of the silver chloride into iodide, disappears during fixing if the thiosulphate solution is strong enough and if sufficient time is allowed.

Toning may be arrested by placing the prints in a 3 per cent solution of sodium chloride (table salt); the prints may remain in this solution until they are transferred to the fixing bath.

667. Thiourea Toning has the advantage that the solution is ready for use directly it is prepared, and keeps well; further, the toning of half-tones and shadows proceeds simultaneously, so that it is possible to stop toning at any moment; with sulphocyanide toning the lighter tones are toned more quickly than the shadows.

¹ Thiourea ($(\text{NH}_2)_2\text{CS}$), which results from an intermolecular change in ammonium sulphocyanide by heating under definite conditions, occurs as small colourless crystals soluble in cold water (9 per cent), and very soluble in boiling water and in alcohol. Both the solid and its solutions keep well.

The complex salts formed by thiourea with gold and silver salts are stable only in an acid medium; moreover, the double silver salt splits up in dilute solution and gives silver sulphide, so that there is a danger of staining the prints when washing them between the toning and the fixing operations. If it is desired to keep the toned prints between toning and fixing, they should be put in water slightly acidulated with an acid (e.g. boric acid, which is without action on thiosulphate).

The following formula gives excellent results. Tartaric acid should be used for gelatine P.O.P., and citric acid for collodion papers—

Sodium chloride	20 g
Thiourea (1% solution)	50 ml
Tartaric or citric acid	0.5 g
Gold chloride (1% solution)	50 ml
Water to make	1000-2000 ml

668. Platinum Toning. Platinum toning (suggested by Caranza in 1856, and used in a slightly different manner by J. Reynolds in 1886) was used, in the days before platinum had attained its present prohibitive price, to obtain beautiful black or warm black tones on mat albumen and mat collodion papers which had been previously toned with gold to a brown colour.

The platinum salt used for toning is potassium chloroplatinite. Potassium chloroplatinite (K_2PtCl_6 —M.Wt. = 415) occurs in the form of small prismatic red crystals, very soluble in water (about 15 per cent in the cold) and insoluble in alcohol; the pure salt contains about 46 per cent of platinum metal; it is unaffected by the atmosphere. The stock solution should be prepared with distilled water and kept in a glass-stoppered bottle in the dark. Toning would be very slow and irregular if this salt were not used in acid solution; the speed of toning depends on the acidity, and not on the actual acid used, but it is necessary to avoid certain acids (such as acetic, boric, formic, and tartaric) which cause more or less rapid decomposition of the bath. Phosphoric acid had long been recommended, but it has no special advantage and its commercial solutions are of uncertain concentration. The best acid to use is sulphuric, or, failing that, sodium bisulphate in equivalent amount (§ 429).

Potassium chloroplatinite	1 g
Sulphuric acid diluted in 10 times its volume of water	50 ml
Water to make	1000 ml

This bath can be used until the platinum is almost completely (90 per cent) exhausted

(Lumière and Seyewetz). The ratio of platinum to silver when no previous gold toning has taken place may vary from 1 : 0.42 (mat albumen paper) to 1 : 0.34 (collodion paper).

Prints toned with platinum should be well washed in several changes of water, and then fixed in an alkaline fixing bath.

Almost identical results can be obtained by substituting potassium chloropalladite for chloroplatinite; this salt gives nearly twice the effect for the same weight.

669. Selenium Toning. The use of selenium in the form of seleno-sulphate¹ (with ammonium chloride added) for toning print-out papers was suggested in 1912 by P. Rehländer as being more economical than toning with gold and platinum. Even with papers which have been well washed to remove the soluble silver salts, toning with sodium seleno-sulphate tends to stain the whites of the images very strongly. This trouble can be obviated, when toning is done after fixing and washing, by adding a small quantity of sodium thiosulphate to the toning solution (Lumière and Seyewetz, 1924). This procedure greatly increases the speed of toning. The tones obtained vary from dark brown to red, depending on whether the image is coarse or fine grained; this toning gives (with certain papers) an appearance of platinum toning when used on a print which has been toned with gold and fixed.

The ratio selenium : silver (1 : 0.88) in a print which has been toned for some time is greater than that for silver selenide (Lumière and Seyewetz). The selenium is deposited on the silver without combining with it until each grain of silver is completely enclosed in selenium.

Sodium seleno-sulphate may be obtained by

¹ Selenium, which in many of its properties resembles sulphur, appears usually as a grey crystalline mass with a metallic reflection; in a fine state of sub-division it is generally red. The alkaline seleno-sulphates, and particularly the sodium salt ($Na_2S_2SeO_6$ —M.Wt. = 205) have a constitution which is closely analogous to that of the thiosulphates ($Na_2S_2O_6$), the selenium replacing a portion of the sulphur. Just as thiosulphate is obtained by dissolving sulphur in a hot solution of sulphite, so seleno-sulphate is obtained by dissolving selenium in hot sulphite solution. As seleno-sulphate is not made commercially it must be prepared as required by dissolving selenium. Solutions of seleno-sulphates should be kept in full bottles, well stoppered to avoid conversion into inactive seleno-trithionates by oxidation; they are more stable in presence of sodium sulphite or thiosulphates. Analogous compounds of tellurium have also been used for the toning of silver prints. All selenium and tellurium compounds are poisonous.

dissolving 30 g of powdered selenium in 1,000 ml of a warm 20 per cent solution of anhydrous sodium sulphite.

Two to 5 ml of this solution are added to each litre of a 30 per cent solution of hypo. The smaller quantity is used for toning albumen papers and the larger for emulsion papers (gelatine or collodion P.O.P.). The bath is clear, colourless, and keeps well.

Toning is very rapid, taking from 2 to 5 minutes, according to the degree of exhaustion of the bath. This toning solution is very economical; 1,000 ml will tone 80 prints 7×5 in. in size, and the results are highly permanent if washing is properly done.

670. Fixation of Print-out Papers. The chemistry and the mechanism of fixation are the same as for negative emulsions (§§ 487-91), but, as we shall see in connexion with washing, the paper support, especially the baryta coating, considerably retards the subsequent removal of the hypo.

Acid fixers, which tend to weaken the detail in the high-lights of the prints, and concentrated solutions, which cause blisters in the washing process, should be avoided. To avoid the excessive swelling of gelatine liable to occur in a neutral bath, an alkaline bath is used. This has the further advantage that, if toning has been carried out in an acid bath, there is no risk of sulphiding.

The following, for example, may be used—

Sodium hyposulphite, cryst. . . .	100 g
Soda carbonate, anhydrous	1.0 g
Water to make	1000 ml

A bath of this kind becomes exhausted very rapidly, and must be frequently renewed. As there is no visible indication that a fixing bath has become exhausted, it should be replaced when about 3 sq ft of paper (e.g. 11 prints 7×5 in.) have been fixed per pint of solution. This is equivalent to 50 sq dm of paper (20 prints 13×18 cm) per litre. A test should also be made as indicated in § 498. The serious worker should use two fixing baths, for the reasons already given (§ 496), and the question becomes one of great importance in the case of print-out papers, owing to the extremely finely divided condition of the silver of the image which renders it very susceptible to any destructive influence.

Although, in warm weather, collodion papers are to be preferred to gelatine papers, the gelatine of the latter can be hardened in an

alum fixing bath, having first made sure that the paper will not leave a greenish tint after fixing and washing. The following bath may be used—

Sodium thiosulphate cryst. . . .	100 g
Acetate of soda, fused	10 g
Chrome-alum	5 g
Water to make	1000 ml

The solution is prepared by dissolving each ingredient separately in a portion of the water, mixing the alum and the acetate of soda solutions, and pouring the mixture into the thiosulphate solution.

If the washing is necessarily rather incomplete, use can be made of an effective hypo eliminator. This will transform the thiosulphate retained by the base into inert sulphate: (but see also § 513).

671. Combined Toning and Fixing. Although suggested in 1850 by le Gray, combined toning and fixing baths were not employed until about 1890, when emulsion-coated print-out papers came into general use. These were the first papers suitable for the combined treatment.

It is generally assumed that prints toned in combined toning and fixing baths last for a relatively short time. It is true that many examples of prints which have proved perfectly permanent after this treatment can be produced, but it is also a fact that these cases are largely exceptional, owing to the deplorable conditions under which these combined toning and fixing solutions are generally used, and owing also to the fact that there is nothing to show when a bath of this kind has been exhausted. Even when all the gold has been exhausted (assuming that there is any gold in the solution; this is not the case in all toning solutions commercially provided ready for use by the amateur), the baths continue to tone; and they tone even when satisfactory fixing is no longer possible.

The prints cannot be permanent unless the toning has effectively gilded the image, and unless the fixing is perfect; these conditions are very rarely combined. It is essential that the combined toning and fixing solution should contain an effective amount of gold, and should not be used for more than a very limited number of proofs.

Finally, it is essential to follow with a separate fixation. This latter is particularly necessary when the required tone is obtained within a very short time of immersion in the solution,

as in this time it is impossible for the fixation to be complete.

A considerable economy in combined toning and fixing baths can be effected by previous fixing of the prints (R. Namias, 1908). Failing this, the precaution already recommended of washing the prints in plenty of water before the toning and fixing should be taken, or alternatively, they should be treated with salt solution and briefly rinsed.

672. Reactions in Combined Toning and Fixing Baths. Combined toning and fixing baths usually contain as essential constituents sodium thiosulphate, alum, a lead salt, and gold chloride.

The reactions between the constituents of the bath themselves and between the constituents and the silver of the image have been studied chiefly by E. Valenta (1892), and A. and L. Lumière and A. Seyewetz (1902-12).

Gold chloride in the presence of sodium thiosulphate is converted into a double thiosulphate of gold (aurous) and sodium (the salt of Fordos and Gélis, which was formerly used for toning daguerreotypes). A mixture containing only these two constituents tones paper prints very slowly and gives only reddish tones.

The toning is accelerated and improved by the addition of a lead salt which, with sodium thiosulphate, gives a double thiosulphate of lead and sodium. The lead in this condition can deposit on the silver, both metals being partially sulphided. A mixture of thiosulphate of soda and a lead salt forms a combined toning and fixing solution which yields very beautiful tones, but prints thus toned change very quickly. A print toned with lead only and then transferred to a gold bath fixes the gold very rapidly; it would seem that the lead compounds previously formed in the image act as mordants. It seems that in a combined toning and fixing bath, containing thiosulphate, gold chloride, and a lead salt, the last-named acts as an intermediary and accelerates the deposition of the gold on the silver; it does not appear in the finished image. A very small quantity (0.05 per cent) of lead salt is sufficient to obtain a maximum effect, and the nature of the soluble lead salt has no effect on the tone nor on the speed of toning. Lead acetate or nitrate¹ is usually used.

¹ Crystalline lead acetate ($(\text{CH}_3\text{COO})_2\text{Pb}_3\text{H}_2\text{O}$ —M.Wt. = 379) commonly called sugar of lead, occurs in the form of colourless dense prismatic crystals, very soluble in cold water (more than 50 per cent), and efflorescing slowly in air.

We have already studied the action of the alums on thiosulphate (§ 493). The alum and thiosulphate solutions are usually prepared separately and mixed at a boiling heat. Under these conditions the reaction between the two salts is incomplete, and several days are required for equilibrium to be reached. A mixture of this kind, without addition of other substances, tones prints by sulphiding the silver; but only dull colours are obtained, and prints thus toned are not very permanent, for the finely divided silver sulphide which is formed is not as resistant to atmospheric action as is the coarse-grained silver sulphide formed by toning development papers. After the addition of gold chloride the mixture tones somewhat more quickly than the double thiosulphate of gold and sodium, but the tones are not as good as those obtained in the presence of a salt of lead. Owing to the presence of salts of lead, the black sulphide of which is insoluble, ordinary combined toning and fixing solutions contain no sulphide; the toned image nevertheless contains a little silver sulphide. It appears that the thionates, formed by reaction in hot solution between the alum and thiosulphate, convert the lead into the most active form for assisting toning.

Combined toning and fixing mixtures supplied in a dry state do not always contain alum; the solution in cold water of those which contain alum results in an unstable liquid which constantly deposits sulphur. The amount of lead is generally increased in these cases in order to convert the sulphides into lead sulphide; this is precipitated with the sulphur as a grey or black deposit.

Toning takes place only in a neutral or acid medium; it is impeded by alkali, and also to some extent by sulphites and bisulphites. Ammonium sulphocyanide is sometimes added to combined toning and fixing solutions; these solutions could also be made with thiourea or its derivatives instead of thiosulphate, but without any particular advantage.

673. Preparation and Use of Combined Toning and Fixing Solutions. The addition of gold chloride to these solutions should be postponed, if possible, until shortly before the solution is

Lead nitrate ($\text{Pb}(\text{NO}_3)_2$ —M.Wt. = 359) is not very different in appearance; it is a little less soluble in water (about 25 per cent), and is unaffected by the atmosphere.

Solutions of these salts in ordinary water are milky owing to the formation of chloride, sulphate, and lead carbonate from the corresponding calcium salts. Lead salts are *poisonous*.

required for use. The following solution is first prepared—

Sodium thiosulphate, cryst.	200 g
Alum	15 g
Lead acetate or nitrate	2 g
Water to make	1000 ml

The three solids are dissolved separately; the alum and the hypo solutions are brought to the boil and mixed boiling. A bulky precipitate is formed with evolution of sulphur compounds. After complete cooling, the solution of the lead salt is added. After several days' standing the solution is filtered; no further precipitate will form.

Shortly before treating the prints, the required quantity of solution is taken and to it is added the gold chloride (1 per cent) solution in the proportion of one volume of the gold solution to 20 volumes of the stock solution. Approximately 120 ml of solution is necessary for 20 prints 7 × 5 in. in size; this number may be increased to 25 if the prints are fixed before treatment. Should this be the case, the bath may be diluted to facilitate the immersion of the prints. As far as possible a quantity of solution greater than is necessary for the number of prints to be treated should not be used, and a fresh bath should be employed for each batch of prints.

In hot climates, and to obtain hardening of the gelatine more completely than that obtained with the solution given above, the following solution, prepared in the cold may be used for gelatine P.O.P. (Lumière and Seyewetz, 1906)—

Sodium thiosulphate, cryst.	250 g
Sodium bisulphite, coml. solution	10 ml
Alum	40 g
Lead acetate	2.0 g
Water to make	1000 ml

Gold is added to this as required, in the manner described above.

For satisfactory permanence, prints must be given an extra fixing.

674. Development of Partly-exposed Prints. Print-out papers with a soluble silver salt in the emulsion can be developed physically (§ 484) to give their normal depth after an exposure of only from one quarter to one tenth of that required for a fully-printed image, using only the silver salt actually present in the sensitive film (Blanquart-Evrard, 1850). This method is applicable only to paper of fresh manufacture which has been kept under perfect conditions and which has been handled only in artificial light or very weak daylight; the less the degree of

printing, the more strictly do these conditions apply.

From the very mechanism of this reaction it is obvious that the print should not be washed before development. Also, dilution of the silver salt in the developer should be avoided as far as possible. As it is necessary to use a perfectly clean dish, one of glass should be chosen. A dish can be dispensed with, however, by placing the print face upwards on a sheet of glass larger than the print, and then covering it with developer by swabbing it rapidly with a plug of cotton wool.

The colour and the contrast of the developed image vary considerably with the type of paper used, the depth of the original image, the actual developer chosen and the degree of acidity of the mixture. Lightly-printed images generally give prints with very poor contrasts.

The following developer (E. Valenta, 1914) may be used—

Citric acid	17 g
Metol	4 g
Hydroquinone	6 g
Water to make	1000 ml

This solution keeps very well in well-stoppered bottles, and is diluted for use to from 10 to 25 times. Preliminary tests should be made on pieces of print to determine what dilution is best for the actual paper used.

When the image has reached the desired depth, development is stopped by immersing the print in a dilute (about 2 per cent) solution of sodium chloride (table salt). After washing, the print may be toned, or treated with a combined toning and fixing bath.

Stain (due to general excessive exposure of the paper to light or to the temperature of the bath being too high) may be avoided, and at the same time the contrast of the image may be increased by adding to the developer a few drops of a dilute solution of potassium dichromate (G. Schweitzer, 1905); up to 5 drops of a 1 per cent solution may thus be added to 120 ml of diluted developer.

SELF-TONING PAPERS

675. Types of Self-toning Papers. The addition to the emulsion of the gold salts necessary for toning prints on print-out paper was suggested before 1860, but it was not until 1896 that P. E. Schoenfelder and E. Kehle worked out a commercial process. For some years past a certain number of *self-toning* or *auto-toning* papers have been prepared which, instead of

gold, have salts of selenium or tellurium in the emulsion.

Emulsions for self-toning papers are made with gelatine or collodion, and correspond to gelatine and collodion print-out papers respectively. Gelatine papers are generally preferred for glossy prints and collodion papers for mat prints.

The extreme simplicity in the handling of these papers and the permanence of the prints when the treatment has been correct have made these papers very popular with amateurs who do their own printing. So simple, indeed, is the manipulation that there is a tendency to take liberties, and so to depreciate the quality and permanence of the prints.

676. Working Methods. Self-toning papers should be used only with vigorous negatives, with the exception of the special papers made for obtaining contrasty prints from weak negatives. The final tone of the image largely depends on the qualities of the negative, within certain limits, the more vigorous the negative, the richer the colour of the print.

Self-toning papers may be placed in the fixing bath without any washing or other preliminary treatment. Most of them can be treated with a solution of sodium chloride (table salt) before fixing to give purplish tones. In both cases, the colour of the image depends essentially on the concentration of the bath, and on the volume of bath used for a given amount of paper. To ensure uniformity of colour when many prints of the same subject are being printed, they should not be treated one by one in the same solution; it is better to measure into a dish the amount of solution required for all the prints, and then to introduce them rapidly one by one into the bath for simultaneous

treatment. The prints must be kept in movement; a good method of doing this consists in continually transferring the print at the bottom of the heap to the top.

The usual strengths of baths are 5 per cent of sodium chloride for the salt solution and from 10 to 20 per cent of sodium thiosulphate for the fixing bath. Acid or alum fixing solutions should on no account be used. The fixing bath should preferably be rendered alkaline by the addition of a pinch of sodium bicarbonate in accordance with the recommendation of most manufacturers.

Very cold baths should be avoided; the best temperature is in the neighbourhood of 65°F. If the toning is done in the fixing bath, and if the temperature is too high, the strength should be reduced by addition of water to avoid the toning being too rapid for easy control.

The volume of bath generally recommended is from 30 to 50 ml for a print 7 × 5 in. (120 to 200 ml per sq ft or 12 to 20 ml per sq dm). Used baths, which have practically no value, should not be used many times in succession, nor should fixing baths which have been used for other sensitive material ever be used for self-toning paper.

Where the above instructions are found to differ in any respect from the makers' instructions, the latter should, as a rule, be followed.

Some self-toning papers become discoloured between the times of their manufacture and use more readily than do other print-out papers, but the coloration disappears during fixing; paper should not therefore be thrown away, owing to its appearance, until it has been tested.

After fixing, the prints should be washed under the conditions (§ 757) described for all other papers.

CHAPTER XLI

PAPERS, PLATES, AND FILMS FOR POSITIVE PRINTS BY DEVELOPMENT

GENERAL CONSIDERATIONS

677. Supports for Positive Materials: Papers. Silver emulsions which do not contain any soluble silver, in fact all emulsions processed by chemical development, are very effectively protected from impurities which may be present in the original paper by an opaque covering (baryta coating) which is employed on nearly all papers not intended for viewing by transmitted light.

Only in certain special cases is it necessary to use papers manufactured from waste vegetable fibres (shreds from clothing factories and clean sorted rags) as is necessary in the case of print-out emulsions containing soluble silver salts. Positive papers are of differing thicknesses and very varying structures. Thin papers are usually used only for small prints; thick papers are employed for large prints and sometimes also for small pictures with large borders which are not to be mounted; thin card is used principally for postcards.

Papers may have a smooth surface, the different finishes (glossy, semi-glossy, and mat) being obtained by the composition and finish of the baryta and by the inclusion in the emulsion of coarse starch or other powdered bodies (barium sulphate, synthetic resins which swell in water, etc.) having a refractive index a little different from that of dry gelatine; papers having a special surface finish are also used (grained, wrinkled, imitation cloth, or satin). Mat papers are coated with a mixture of lower gelatine content than glossy papers and are not calendered after baryta coating.

The image is always sharper and more contrasty (§ 590) on glossy papers than on semi-glossy and mat papers. Very small images and images of all sizes which are of scientific or documentary interest and all photographs which are destined for reproduction, should be copied on glossy paper; (nevertheless smooth mat papers are useful for preparing originals for catalogues, since these are more suitable for retouching (§ 865) and the retouched portions match the unretouched portions better): photographs of artistic interest may with advantage be copied on paper the structure of which is smaller than the image dimensions, the picture

being viewed from a distance; in this way it is possible to avoid reflections, which are always a nuisance when viewing large glossy prints, to soften detail (and graininess in the case of enlargements) and to encourage the spectator to stand back and observe the picture under good conditions.

Baryta-coated papers cannot be folded or creased, especially when dry, without cracking at the fold; it is better to use non-baryta-coated paper for documents which have to be handled frequently.

In order to diminish the bulk of archival documents, papers are sometimes used which are coated with emulsion on both sides, the paper being temporarily dyed brown in order to protect each side in turn whilst exposing the opposite side. Translucent papers, which are more or less transparent, are used for decorative or advertising purposes; they are also used for the preparation of reduced scale drawings laterally reversed, the negative thus obtained being used as a master for the preparation of copies necessary in engineering or other work. Finally very agreeable effects can be obtained on these papers by colouring on the back and exhibiting against a white card, or by using them against variously coloured backgrounds.

Another device which is sometimes used for advertising purposes by day and by night, consists in producing two separate images, in register, on either side of a translucent support (such as opal film or very homogeneous paper) the front image being suitable for viewing by reflected light but having insufficient contrast if illuminated from behind, and the rear image (which may be diffuse) of suitable density to re-establish the contrast if viewed in this way. In such a paper the contrast passes from 1:40 to 2:53 and the maximum density from 1:30 to 3:64 when the image is viewed as a transparency instead of by reflection.

A special type of paper may be used for obtaining an image directly on any type of support and this is employed particularly to replace manual tracing on sheet metal used in aircraft construction. After the support has been treated with a varnish and allowed to dry, it is rendered

adhesive by the application of a suitable liquid and the sensitized surface of the paper squeezed into contact. When dry, the paper which has acted as a temporary support to the emulsion (a high contrast emulsion of a type suitable for line reproduction) is stripped away and the emulsion exposed by contact or projection.

Finally, mention may be made of stripping papers from which the image may be transferred to all kinds of supports (such as metallized papers, wood, opal glass, etc.) after processing and drying: a treatment with warm water dissolves the substratum of unhardened gelatine which had previously held a tanned layer of emulsion to the temporary paper support.

For some scientific or technical purposes, methods are sometimes adopted to reduce curl which might be caused by stretching or swelling of the emulsion. Curl may be considerably reduced by the use of a paper which has been varnished or which has been laminated with a thin sheet of aluminium foil. Another method is to use a paper which has been coated on the back with unhardened gelatine before use; the paper is moistened with water to give maximum expansion and laid down on a sheet of glass. It adheres firmly to the glass and is dried at its maximum extension, so that any further curling during later treatment is prevented.

678. Photographic development papers are supplied in sheets, in envelopes containing 10 to 20 sheets (or in cylindrical cardboard containers in the case of the larger sizes) or in boxes of 50 or 100 sheets, or sometimes in roll form in lengths of 10 to 100 metres. The sheets are generally packed all the same way up except for the last sheet which is reversed to prevent contact of the emulsion with the wrapping paper. There is little fear of error in determining which is the sensitized surface of the paper since this is generally slightly concave and the back of the paper often bears a trade mark printed in grey. If the interior wrapping is of waxed paper care should be taken to avoid contact of this paper with the emulsion since traces of wax deposited on the emulsion surface will stop or retard locally the action of the developer; the top sheet of an opened packet of paper should therefore be turned over before re-wrapping.

If it is necessary to cut up large sheets of paper it is advisable to plan the work carefully to avoid wastage of paper; the unused paper should be handled only with clean, dry hands and care should be taken to avoid fingering the

emulsion surface; for preference two sheets should be placed with emulsion face to face when cutting. It is often convenient to place the sheets of paper destined for immediate use in a separate light-tight box in order to avoid frequent wrapping and unwrapping; the box should be marked clearly to indicate the type of paper and its contrast grade.

679. Positive Plates. There are two types of diapositive (from the Greek "dia" meaning "through," indicating that a positive image is to be viewed by transmitted light) or lantern plate available on the market, the first carrying a slow gelatine-bromide emulsion to give black tones (some manufacturers supply them in two contrast grades; alternatively "Process" type plates may be used for document reproduction) and the second carrying a much slower fine-grain chloride or chlorobromide emulsion to give warm tones. Diapositive plates are sometimes supplied at special request with a mat translucent emulsion to avoid the necessity of backing with ground glass when the photograph is to be used for direct viewing. Some manufacturers also supply plates made of opal glass coated with a black-tone emulsion to be used for photographs to be viewed by reflected light.

680. Positive Films. Besides cine-positive films, the emulsions of which are much faster than those normally employed for positive plates, and which are normally made in only one contrast grade, slow negative films of different degrees of contrast are often used for making transparencies. In this way it is possible to make in one piece positives of much greater dimensions (width 1.20 metres and of any length) than is possible to coat glass plates. The use of film is also an advantage where collections of slides for projection have to be circulated, since they can be readily mounted under glass when they reach their successive destinations.

A number of types of lantern-slide projectors permit the projection of still pictures printed on strips of 35-mm cine-positive film similar to miniature negative film; a mechanism in the projector moves the film on frame by frame as required. The positive films may also be cut up and the separate pictures mounted in metal or cardboard frames so that they may be projected in any desired order. Automatic projectors for advertising purposes use an endless loop of film on which are printed 35-mm still pictures. Films coated on both sides are used for making two-colour copies or for stereoscopic anaglyphs; one of the emulsions is coated on

top of a non-actinic but decolorizing sub-coat (L. Gaumont, 1909), or both emulsions are temporarily dyed an intense yellow (P. D. Brewster, 1913), in order to avoid affecting each layer in turn whilst the other is being exposed.

681. Emulsions which may be coated by the User. The needs of the aircraft industry during the Second World War have induced manufacturers to supply emulsion ready for coating or preferably, because of their greater stability, dry powdered emulsions which may be dissolved in a prescribed quantity of warm water. These emulsions may be coated on any type of support which has been pre-coated with cellulose varnish or some other suitable impermeable medium which will not attack the sensitive material. On small surfaces, coating may be carried out on a whirler, centrifugal force ensuring the uniformity of the coating. On large surfaces, the emulsion is sprayed on to the support (preferably held in a horizontal plane) by means of a spray-gun of the type used for painting (following the technique advocated in 1934 by E. Mollo for decorating large expanses of wall). These guns must have all parts which come into contact with the emulsion made of pure nickel, stainless steel, or other metal thickly plated with silver. The coating operation should be carried out if possible in an atmosphere of 72°F to 77°F and of relative humidity 60 to 70 per cent; the gun should be held at a distance of about 18 in. from the surface to be sensitized; if the emulsion has been dissolved in about 12 times its weight of water, the optimum air pressure is from 3 to 3.5 kilogrammes per square centimetre. The coating operators should be provided with masks which filter the air through sheets of wadding to remove the dust formed during spraying (the same precaution should also be taken during the preliminary varnishing treatment). Spraying may be conveniently controlled by the inclusion of a red dye, which may be removed in the course of the normal treatments, and which appears black or dark grey in the green safelighting employed (T. T. Baker, 1945).

682. Different Types of Emulsions. The preparation of positive emulsions for coating on plates or films differs very little from the preparation of those for negative emulsions: for example, reduction of the iodide content and sometimes the omission of this salt in silver-bromide emulsions, the presence of chloride or the replacement of bromide in silver chlorobromide or chloride emulsions, precipitation as

finer grains and a shorter time of digestion. Since the covering power of fine-grained silver is greater than that from the coarser-grained negative emulsions, the emulsion is coated more thinly and has a lower silver salt content, resulting in more rapid development, fixing, washing, and drying.

683. Emulsions for coating on paper differ essentially from negative and diapositive emulsions in that their first digestion is much shorter and is not generally followed by washing to remove soluble salts, nor in consequence is it necessary to digest the remelted emulsion since this would have no effect. Thus whilst the soluble salts left in the emulsion after precipitation of silver halide crystallize on the permeable support during drying, they later divide between the emulsion and the permeable paper support so that there is no further risk of crystallization.

These emulsions are very strongly hardened and in general do not dissolve even in boiling water (except those for special purposes such as papers for the Bromoil process); for this reason they may be dried at the high temperatures demanded by certain classes of user, for example in D and P work for amateurs. The emulsion is plasticized by the addition of a very small quantity of glycerine which prevents excessive curling of the unused paper. The fact that the maximum density by reflection corresponds approximately to a transmission density of about 1.2 (§ 600) and the fact that the covering power of the silver is the greater the finer the grain, results in reducing the mass of silver (calculated as metal) per square metre to about 3 g for silver bromide papers and 1.5 g for silver chloride papers. This difference in silver content explains a number of differences in the behaviour between images produced from silver bromide and silver chloride. It explains for example, the fading of chloride images dried at excessive temperatures; the different results obtained when using various reversal baths, stopping in the case of chloride images, the processes which set in train the reactions in which the silver of the intermediate negative or positive take part, etc. Finally, most positive papers with a glossy surface are protected from abrasion by a very thin coating of gelatine. On a paper bearing an emulsion layer and anti-abrasion layer of total thickness 0.01 mm, the thicknesses of the two layers after swelling in water became 0.04 mm for the emulsion and 0.005 mm for the anti-abrasion layer (E. Schloemann, 1932). It has been proposed, in order to reduce the

risk of sticking to the cloths of drying machines to use insoluble coatings (porous collodion, agar-agar, etc.).

Some years ago, the speed of special enlarging papers was considerably increased, without modification of the other characteristics, by incorporating in the emulsions sensitizing dyes (cyanines), of which the effect is limited to the blue-violet region of the spectrum (with the maximum about $475\text{ m}\mu$ and the limit about 510 to $520\text{ m}\mu$). It has thus been possible to manufacture chloro-bromide enlarging papers and even chloride papers with speeds to incandescent lamps about three times those of corresponding papers which have not been sensitized in this way (O. Bloch, 1931). It may be noted that the colour sensitization of positive papers by means of eosine had been suggested in 1900 by K. Kieser in order to obtain a better rendering with incandescent lamps, but the fact that the sensitization extended into the green made it necessary to use a red light of very feeble intensity for processing. Black-tone paper positives prepared by normal development methods generally remain in perfect condition for two years or even longer; the ageing of warm-tone papers, particularly when the emulsion is in an acid condition, often results in blacker tones.

The maximum density, the speed, and the contrast (particularly in the case of high contrast papers), sometimes slowly fall after keeping for a long period in a not too dry atmosphere. Papers are best kept at 15 – 18°C in an atmosphere of relative humidity 50–65 per cent. Packets of paper should never be exposed to the sun. Old papers, which give veiled or mottled prints may often be made to yield perfect prints by processing in a developer containing an addition of an antifogging agent (§ 386) such as benzotriazole; in this case the exposure should be somewhat increased.

It is not possible to avoid minor variations in the speed and contrast of successive batches of the same type of paper, the latter being more troublesome than the former, thanks to the exposure tolerance of positive papers. Latent-image fading is considerably more rapid in the case of unwashed emulsions, particularly chloro-bromide emulsions, than in negative emulsions; cases have been noted where fading has been very appreciable on prints developed 4 hours after exposure and where the latent image was totally destroyed after 10 to 30 days, it being possible to use the exposed paper again as if it were fresh.

684. Silver-bromide papers, of which the true sensitivity is limited to the spectral range 380–470 $\text{m}\mu$ are much the fastest. They are used principally for enlarging and the tone of the image is normally a neutral black. Silver chloro-bromide papers are made in a large number of varieties containing different relative proportions of silver chloride and bromide: papers with only a small chloride content differ very little from bromide papers and those with a low bromide content are similar in properties to chloride papers. The spectral sensitivity and speed of these papers is intermediate between those containing only one of the halides. They usually produce a warm black image but some, by use of an appropriate developer, will produce a range of tones from warm brown to sepia.

Silver chloride papers, which have a true sensitivity limited to the spectral range 370–420 $\text{m}\mu$ are much slower than bromide papers. The image colour is a cold black or even a blue black, and the latter tendency is often increased by the use of emulsion addition agents (§ 191) or additions to the developer. Papers containing silver chloride when exposed to daylight rapidly turn violet, the colour being more intense with increasing chloride content. On the other hand, silver bromide slowly turns grey, so that it is quite simple to differentiate between the various types of sensitive material in this way.

The particular characteristics of chloride papers are such that they are almost exclusively used in the preparation of contact prints for amateurs by D and P works. The increased speed of these papers due to the use of sensitizers also now enables them to be used for enlargements but it is necessary to use a more intense light source than that usually available in amateur enlargers.

The relative speeds of the various types of sensitive material are indicated very roughly in the table given below—

Fast negative emulsions	200,000
Cine-positive film	5,000
Black-tone lantern plates	3,000
Bromide papers	1,500
Warm-tone chloro-bromide papers	130 to 500
Chloride enlarging papers	20
Contact chloride papers	5 to 7.5
Warm-tone lantern plates (according to the colour desired)	1 to 25

685. Sensitometric Characteristics of Positive Papers. Reciprocity failure (§ 205) is much greater in the case of positive papers than for

negative materials. Exposure to low intensity illumination considerably reduces the maximum density and hence also the contrast, since the range of luminosities remains constant. The fact that low-intensity exposure of print-out papers frequently increases contrast, has some-

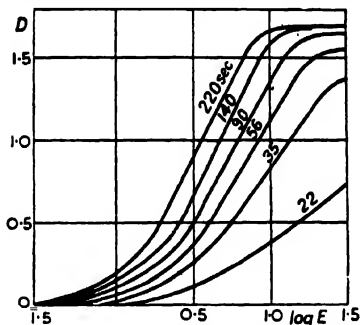


FIG. 41.1. CHARACTERISTIC CURVES OF BROMIDE PAPER WITH VARYING DEVELOPMENT TIMES

times been unduly generalized to include development papers. It has been clearly established by different experimentalists (Ilford laboratories, 1925; F. Formstecher, 1929) that exposure to low intensities never increases contrast but frequently reduces it and also the maximum density.

On the other hand, sensitometric tests using constant intensity and variable exposure time give very different characteristic curves from those obtained using constant exposure time and variable intensity, which are comparable conditions to those found in practice. In some instances the differences between papers may be almost eliminated by this effect.

The curves shown in Fig. 41.1, which are taken from the work of L. A. Jones and C. A. Morrison (1939) correspond to sensitometric tests in which the exposure time was kept constant and the illumination varied, values of illumination being chosen near the optimum for each type of paper.

A feature which is common to all positive papers is the behaviour of the corresponding curves of specimens exposed under identical conditions and developed for increasing times in the same developer (the curves in Fig. 41.1 correspond to a glossy silver-bromide paper: the times of development in seconds are indicated on each curve). As soon as maximum gamma has been reached (after 140 seconds in the example being considered), further development

merely shifts the curve in the direction of decreasing exposure, so that identical images could have been obtained using different exposures, a shorter exposure being compensated for by increasing the time of development. Most good quality papers will tolerate a time of development which is double that which is necessary to give the maximum black, without giving veiled or mottled whites. Within this range prints are identical when the product of exposure time and development time is constant (B. T. J. Glover, 1922).

The exposure tolerance, which reaches 8 : 1 on some very low-contrast papers, is not more than 1.5 : 1 on very high-contrast papers. Since the fog becomes greater with increasing development it is not always an advantage to use the shortest exposure time giving the maximum black of the paper.

686. The characteristic curves of the three types of paper previously defined have different shapes: Fig. 41.2 shows curves of samples of three different glossy papers having the same contrast and maximum density; one is silver bromide (curve B), another chloro-bromide (CB) and the last chloride (C). Two of these curves have been plotted so that the exposure

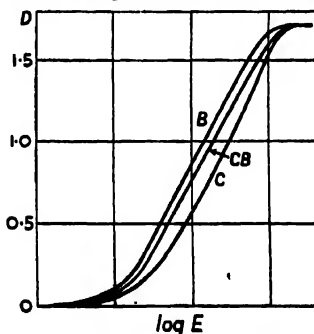


FIG. 41.2. CHARACTERISTIC CURVES OF (B) BROMIDE PAPER, (CB) CHLOROBROMIDE PAPER, AND (C) CHLORIDE PAPER

ranges coincide with that of the third curve. Curve B has the longest straight-line portion (from a density of about 0.5 up to a point about 0.2 below the maximum density). Against this, the straight-line portion of curve C is very short, being approximately between a density of 1.2 and 1.5. One might almost say that the slope of the curve increases steadily up to the region of maximum density and in this case the conception of gamma has no practical

significance. It has been suggested that emulsions of this type, which we have seen give the best compensation in printing negatives having a long toe (§ 605; curves *A* of Fig. 37.3), be termed "orthograde" (M. Abribat, 1935). Curve *CB*, which represents a chloro-bromide paper

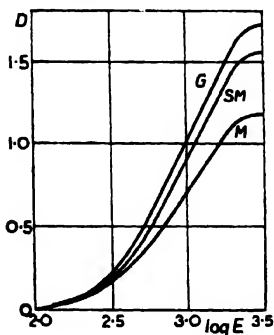


FIG. 41.3. CHARACTERISTIC CURVES OF (G) GLOSSY, (SM) SEMI-MAT AND (M) MAT PAPERS

containing a dominant proportion of bromide, has a shape intermediate between curves *C* and *B* but is closest to the latter. Superficial reduction of an over-exposed print produces some suppression of the toe of the characteristic curve, a result which gives interesting effects and is mainly useful for increasing the high-light contrast (E. Mankenberg, 1943).

According to whether the characteristic curve has a short or a long toe, the paper is more suitable for printing under-exposed negatives or negatives having very contrasty high-lights (pictures taken against the light).

687. The nature of the paper surface has a considerable influence on the maximum density (§ 590) and gamma. The curves shown in Fig. 41.3 correspond to three fractions of the same bromide emulsion coated respectively on glossy (G), semi-mat (SM), and mat (M) papers. It will be seen that the range of exposures is the same for the three kinds of paper, but that the maximum black and gamma are less as the surface becomes less glossy. It should be remembered that these differences disappear when the images are illuminated by polarized light and viewed through a polarizer oriented so as to extinguish the reflected polarized light (§ 122), the maximum black being greater than that from a glossy print viewed by ordinary light.

688. **Different Degrees of Contrast from the Same Type of Paper.** With the exception of certain luxury papers, specially designed for portraiture, which are made only in one degree of contrast (medium or soft), positive papers are always made in several degrees of contrast or grades, the number of grades being as many as seven in the case of those papers destined for amateur use. Some establishments which cater for amateurs, systematically use papers of excessive contrast, believing that the amateur always expects to obtain results composed of black and white and does not bother about the intermediate tones.

The curves of Fig. 41.4 show six grades of glossy chloride paper; the curves have been separated to avoid overlapping and without this separation they would coincide in their upper parts, the minimum exposure to obtain maximum black generally being the same for papers of the same series.

Since these papers all have the same maximum density, it will easily be seen that a variation in maximum gamma (or the maximum average slope for those papers for which it is not possible to assign a value of gamma) determines in the inverse sense (and almost inversely

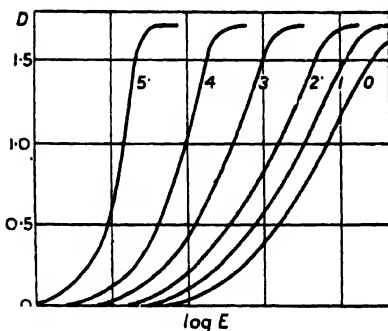


FIG. 41.4. CHARACTERISTIC CURVES FOR SIX GRADES OF GLOSSY CHLORIDE PAPER

proportionally) the density interval between different intensities.

The following table gives some idea of the usual designation of the grades 0 to 5 of the papers under consideration, and the values (natural and logarithmic) corresponding to the different intensities; it should be remembered that perfect agreement between a paper and a negative is assured when the difference between the extreme densities of the negative (§ 606) is

equal to the difference between the logarithms of the extreme intensities which determine the useful intensity range (§ 603). When the difference ΔDn of the extreme densities of a negative falls between the values $\Delta \log Ep$ of the useful range of two grades of paper, it is preferable for high values of ΔDn to choose the grade of paper for which ΔDn is higher than $\Delta \log Ep$; conversely, for weak negatives the grade of paper should be chosen for which ΔDn is lower than $\Delta \log Ep$ (L. A. Jones and C. N. Nelson, 1942).

Curve No.	Intensity Range		Usual designation
	Natural value	Logarithm	
0	30	1.48	extra soft
1	26	1.41	soft
2	20	1.30	normal
3	15	1.18	medium
4	9	0.95	contrast
5	5	0.70	extra contrast

These designations vary somewhat from one manufacturer to another; certain brands of paper also include an ultra-soft and ultra-contrast grade, having intensity ranges of 100 and 2 (or logarithmic values of 2.00 and 0.30).

In certain brands the softest bromide paper is softer than the softest chloride paper and the most contrasty chloride paper is more contrasty than the most contrasty bromide paper.

From the table above it will be observed that the differences between the logarithms of the intensity ranges increase with the contrast (Curve No.); it would be preferable if the values of the difference of these logarithms decreased with contrast.

689. Methods of Varying the Contrast of a Paper. Papers having a contrast which may be varied over a range of values have been realized (K. Fischer, 1912; R. Risson, 1935; F. F. Renwick, 1937) by mixing two emulsions, one very soft and the other very contrasty and of different colour sensitization. Such a paper made from a non-chromatized soft chloro-bromide emulsion and a contrasty chloride emulsion sensitized to blue-green, may be handled in orange light. It may be adapted for all negatives having a density range between 2.0 (expose to blue light) and 0.8 (expose to yellow light) by making use of a shutter arrangement to vary at will the proportion of the two lights so that the time of exposure of the same negative remains constant as one passes from one extreme light to the other.

The intensity range of a paper may be extended by using an auxiliary light source and reducing the time of development to the minimum necessary to obtain a maximum black (K. Kieser, 1926). The auxiliary light source reduces the high-lights of the print more than the detail in the shadows, but it should be noted that this method should be reserved for use in cases where only a small variation on the paper scale is required (P. Delmotte, 1942). Another method consists in immersing the paper, between exposure and development, in a 0.1 per cent solution of potassium iodide for about 30 seconds followed by a quick rinse, the loss of contrast due to iodizing being compensated for by increasing the time of development (F. Burki and L. Jenny, 1941).

On certain papers, the use of a light yellow filter (with half-watt illumination) and approximately doubling the time of exposure gives an increase of 10 to 75 per cent in the intensity range and this method may therefore be used in copying negatives with density ranges which exceed their normal value by from 0.04 to 0.24 (F. Formstecher, 1926-9). The effect of a coloured filter is greatest in the case of a negative having an image colour which is not neutral, and is particularly great for a negative toned with a dye whose densities follow the spectral composition of the copying light. Such a negative constitutes what R. Luther (1911) has called a universal or "elastic" negative. By very large variations in the time of development and exposure (in the inverse direction) of silver chloride papers, it is possible to vary very appreciably the density corresponding to the mean exposure intensity, without affecting the high-light and shadow densities, thus modifying the relative contrast in high-lights and shadows (E. Mankenberg, 1943).

Contact prints made using opal glass have a slightly higher image contrast than if clear glass is used, providing precautions are taken to see that the intensity and quality of the light is the same in both cases; in a series of experiments on different types of paper the contrast factor was 1.1 times as great (C. Tuttle, 1934); it seems that this effect is due to multiple reflections taking place between the negative and the opal glass, all the effective densities being lowered but with a maximum effect on the low densities.

690. The Herschel effect (§ 209), which is very large on some slow papers, may be used to lower the contrast of prints from hard negatives:

after exposure to white light a prolonged exposure is given to red light, the effect being greatest in the most strongly exposed parts of the print (P. Strauss, 1928).

J. Sterry (1904) found that about a minutes' immersion in a solution of potassium bichromate (at a strength of 1 per cent for bromide papers or 0.2 per cent for chloride papers), followed by a 20-second rinse in water, between exposure and development, considerably reduces the image contrast (§ 392). E. O. Langer (1937), obtained the following results using a constant concentration of potassium bichromate (0.5 per cent) for 30 to 60 seconds in the case of fast papers and 1 to 2 minutes in the case of slow papers.

Paper used in the experiment	Intensity range		Increase in negative density range
	Before treatment	After treatment	
Contrast bromide	11	125	1.05
Soft bromide	63	350	0.74
Extra contrast chloride	4	22	0.74
Soft chloride	32	500	1.19

F. Formstecher (1933) has shown that treatment by all oxidizing agents, between exposure and development, increases the length of the toe of the characteristic curve. These effects are largely influenced by the concentration of soluble halide in the emulsion concerned (Lüppo-Cramer, 1929). Whatever the oxidizing agent, preliminary experiments should be carried out on samples of the same paper. The same treatments are applicable to positives on plates and films, especially for the production of duplicates by successive copying.

691. On certain papers, the intensity range may be varied by altering the conditions of development. Thus on a soft bromide paper the range may be increased by about 30 per cent (corresponding to an increase of 0.11 in the density range of the negative) by using a weakly bromided developer (E. Schloemann and E. Weyde, 1933).

On another soft bromide paper, it was found possible to double the range by using a very dilute developer (W. F. Weiland, 1940).

Variations in the composition of the developer are mainly for the purpose of varying the maximum density, the curves overlapping in their lower and middle parts (U. Schmieschek, 1942).

Two-bath development (§ 477) in which the first bath was a solution of sulphite and developing agents and the second an alkaline bromide solution, gave a reduction in gamma on a high-contrast paper of from 8 to 4.7, the inten-

sity range covered changing from 2.8 to 12.5 (corresponding to an increase of 0.55 in density range) (F. Formstecher, 1930). The use of the same solutions in the reverse order, lowered both the gamma and the maximum image density, the increase in the intensity range being appreciably less.

The intensity range may also be increased by transferring the paper, after a short development, to a still bath of pure water (§ 389) (H. W. Bennett, 1933).

Another method which is applicable only to prints made by projection, will be described when dealing with enlargements.

692. **Abrasion.** Papers, especially gelatine chloride and those with a glossy surface, are very susceptible to friction. Stress marks, the result of friction or abrasion, show in the same manner as on negative emulsions (§ 200), as black lines on a light ground, or as light lines on a dark ground. The markings which result from abrasion or friction can be minimized by "neutralizing" the outside surface during development by adding a very small quantity of a soluble iodide to the developer, which superficially desensitizes the emulsion. Fixing is then very slow and necessitates the employment of a more concentrated bath. The effects of friction can also be lessened by the addition of small quantities of hypo to the developer, but this introduces the risk of yellow stains of the same nature as dichroic fog.

Although these remedies are suggested, it is very desirable to avoid all friction or rubbing of the surface of a paper, however slight. Special care should be taken to prevent the sheets of a packet from sliding over each other.

693. **Exposure to Light.** Bearing in mind that the illumination decreases very rapidly in strength as the distance from the lamp becomes greater (§ 11), uniform results cannot be expected unless the negative is kept at a fixed distance from the lamp. This applies equally whether systematic tests are made for obtaining the best time of exposure, or whether a series of prints is required from one plate. This condition is secured automatically when a printing box is used. When printing in a frame the most simple method of obtaining these conditions consists in placing the lamp on a table in a marked position, and drawing lines on the table to indicate various positions for the frame. On each one of these lines make a note of the largest plate which can be illuminated sufficiently uniformly in that position, and also

the relative values of equal times of exposure. These lines can be drawn at distances from the lamp proportionate to the square roots of the numbers 1, 2, 4, 8, 16, 32, etc. These are, approximately, 1, 1.4, 2, 2.8, 4, 5.6, etc. Under these conditions, equivalent exposures are practically doubled when the frame is moved from any line to the next.

When giving exposure times inversely proportional to the illumination, the effective exposure diminishes slightly in proportion as the illumination decreases; the photographic efficiency being, with almost all papers, less as the lighting becomes less intense. But this effect is, as a rule, of a practical significance only when the illumination is very considerably reduced.

694. Experimental Determination of the Exposure. The actual time of exposure ought not to be very short, unless some automatic exposing device can be adopted, as a slight error assumes relatively a considerable importance. At the same time, it should not be so long as to restrict unduly the number of prints produced. When the exposure is made by hand, the intensity of the light,¹ and its distance from the negative, should be so arranged that the exposures should be, as far as possible, from 10 to 30 seconds.

The following working conditions may be adopted as a rough guide—

Bromide papers	} 10 watt lamp at 4 ft
Transparencies, black tone	
Chloro-bromide papers	} 15 watt lamp at 18 in.
Chloride or gaslight papers	
Transparencies, warm tones	} 60 watt lamp at 12 in.

Although with practice it is not difficult to learn to count seconds, it is always preferable to rely on some mechanical time indicator. It ensures uniformity in prints taken from the same negative. The most practical indicator for this purpose is the metronome, adjusted to beat seconds or half-seconds.

695. Even the most experienced professional printer cannot avoid making errors from time to time in estimating the exposure for taking a print from a particular negative on a certain paper. Those who print only occasionally are very much more liable to make such mistakes, especially if they are using a paper with which they are not familiar. Rather than run the risk of spoiling several sheets of paper in succession,

or of obtaining only inferior prints, it is infinitely preferable to sacrifice a small piece of paper for making tests. A piece of the same paper which is to be used for printing is used for making a series of exposures in steps, suitably adjusted to the negative.

A series of exposures so arranged that each shall be twice the preceding—so forming a *geometrical progression* in the ratio of 2—will allow the best time of exposure to be determined within a very long range, and by the use of the minimum of time and paper. It is, in fact, a general law in photography that exposures in a constant ratio produce images in which the differences are practically equal. The number of test exposures to be made will obviously depend on the experience already acquired: the first estimate is much more likely to be correct if the photographer has already ascertained the most satisfactory exposures for negatives which differ only slightly in character and if prints have been taken on the same paper under identical conditions of lighting.

The beginner should try, for example, exposures of 4, 8, 16, 32, and 64 seconds. Within this range it is practically certain that the correct exposure will be found. A more experienced worker can limit his tests to two exposures, 12 and 24 seconds, for example. It is not desirable, particularly at the start, to endeavour to economize paper in these tests. It is essential that in each of the test exposures it should be possible to examine satisfactorily the rendering of the lights and shadows, especially in the chief points of interest.

The printing frame, containing the negative and the piece of paper for the test, is covered with an opaque shield—a piece of card, thin sheet metal, etc.—and placed at the correct distance from the lamp, accurately adjusted. If, for example, it is desired to test the five times of exposure previously suggested, the shield, completely withdrawn for four seconds, will be placed so as to cover about one-fifth of the test-piece at the expiration of that time. Then the shield will be moved forward so as to cover an additional portion of the paper at successive intervals of 4, 8, 16, and 32 seconds.

The different portions of the paper will then have been exposed respectively for—

4	= 4 sec
4 + 4	= 8 ..
4 + 4 + 8	= 16 ..
4 + 4 + 8 + 16	= 32 ..
4 + 4 + 8 + 16 + 32	= 64 ..

¹ In automatic machines and in some models of printing boxes, the illumination can be varied, not by altering the distance between the plate and the lamp or lamps, but by regulating the intensity of the electric lamp by reducing the voltage more or less by means of a rheostat.

The exposed test piece should be developed at once under the conditions which will be described later for each variety of paper, the time of development and the temperature of the solution being very carefully noted.

The different parts of the test piece will show images increasing in density; that which best represents the tone values of the subject will be selected. Assuming that the development has been correctly carried out, if all the images are too light, all the exposures have been too short; if, on the contrary, all are too dark, all the test exposures have been too long. In either case the test ought to be repeated either by using a lamp of greater or less intensity, or by modifying the distance between the printing frame and the light, or by adopting a new series of test exposures. Should one of the partial images be a little too dark and another slightly too light, a fresh test is unnecessary; an exposure intermediate between those corresponding with the two images respectively may be adopted.

It is obvious that the development of the test piece might be shortened, thereby preventing the image from attaining excessive density. But in that case the blacks would not possess that rich quality which characterizes a normally developed print.

If the light tones are correctly represented on one of the partial images, and the shadows on another, it is a sign that the paper selected is not suitable for printing from that particular negative. The test should be repeated on a paper exactly suited to the negative. It must be borne in mind that though two papers may have their full gradation within the same limits, they may render the intermediate tones very differently. The transition may be practically uniform in one, and very abrupt in the other. Two papers possessing the same extreme contrast may thus be very different in their general character.

If the shadows are correctly reproduced with an exposure shorter than that which gives the best rendering of the light tones, a paper which gives softer contrasts should be used. On the contrary, a paper giving greater contrast should be selected if the shadows are correctly rendered with a longer exposure than that required for the light tones. In either case, a test for the correct exposure should be made on the new paper.

It is possible to obtain commercially screens which have 6 or 8 stops of uniform densities

suitably spaced to provide a complete range of exposures when placed over a negative. The screen is placed between the glass of the printing frame and the negative for which the exposure time is required and a trial exposure made. The correct exposure for the negative is obtained by dividing the exposure time used for the trial by the opacity of the strip which corresponds to the best reproduction in the print.

The best exposure being known, any desired number of prints may be then made and the development deferred to allow of the simultaneous treatment of all the prints from the same negative. An essential condition is that they should be developed in exactly the same manner as the test piece, the developer being identical in composition and temperature.

696. Urgent Prints. In certain cases, as, for example, current events for the daily Press, topical cinematography, military operations, etc., one or more prints may be required in the shortest possible time after exposing the negative. The print is then taken from the wet negative, either before or after fixing. It must be remembered, however, that the silver bromide in the unfixed film forms an image complementary to the negative, the contrast of the negative image being thereby considerably reduced. Also, a temporary fixing in an acid solution with a brief rinsing will require as much time as a thorough fixing in a fresh hypo bath of suitable strength.

Gelatine which is soaked in a strong solution of hypo is less likely to melt in the projector than gelatine soaked in plain water, since the latter will be more swollen. The use of a mercury vapour lamp will reduce the risk of excessive heating of the negative.

Printing from a negative which has been fixed, very rapidly rinsed and surface-dried, is best carried out by means of an enlarger. If absolute sharpness is not essential, a print may be made by contact. The sensitive paper should be protected against actual contact with the negative impregnated with hypo by the interposition of a very thin sheet of celluloid of ample size, applied to the negative with a squeegee. On account of possible bad contact, diffused light should be avoided as far as possible. The image will be slightly sharper if the print is made at a long distance from a light as small as practicable, the frame and the lamp being kept perfectly still during the exposure.

In the case of a negative which has not been fixed but development stopped by means of an

acid bath,¹ the sensitive paper may be applied directly to the negative by means of the squeegee (gelatine in contact with gelatine). The paper should be previously moistened with water and the exposure made in the usual manner after wiping the glass side of the negative, or after placing on a sheet of glass in the case of a film negative. It should be remembered that the sensitivity of the paper is somewhat less when wet.

It has been suggested (A. Batley and B. Beilenson, 1941) that the surface of the paper should be coated with a varnish which is impermeable to water but which will dissolve in the alkali of the developer. In this way the paper may be placed in direct contact with the wet negative.

697. Soaking before Development. The development of prints on paper is considerably facilitated if they are wetted before development. This prevents the paper from curling in the developing solution, and also lessens the risk of air-bells forming on the surface, a risk to which rough papers are specially liable. It is very easy to ascertain if air-bells have formed by examining the print close to the light, and, if any are seen, to ensure the uniform wetting of the surface by passing a brush or a tuft of cotton wool (thoroughly wetted) over the whole surface of the gelatine. The addition of a wetting agent to the water greatly increases the efficiency of this treatment.

698. Development. A print on paper can be considered perfect only if development has been sufficiently prolonged to produce the strongest black (except, of course, in the case of warm-tone papers) which the paper in use can give, without, however, being carried to such a stage that the whites are degraded. When it is desired to utilize only a part of the scale of tones, e.g. from white to a medium grey, as in portraits of children, mist effects, etc., the paper should be selected and the exposure regulated so as to produce only a grey under the thinnest part of the negative. But development should be carried as far as in the case of a print having full blacks. It is only on this condition that the intermediate tones can be correctly rendered. A curtailed development produces, as a rule,

only greenish or yellowish images—very unsuitable for after-treatment—sulphide toning, bromoil, etc. A very short development will even produce an irregular image, certain parts being more fully developed than others.

The image in reduced silver is black only when the size of the grains of silver is within certain limits. Very fine grains, corresponding with the incomplete development of the grains of the silver halide, are yellowish and remain yellowish after sulphiding. Their colour can be improved only by intensification, producing an appreciable increase in their size.

The speed of development of images on paper has often been attributed to the penetration of the developer through the paper base, but the permeability of the support plays no part. A paper of which the emulsion surface has been covered with a waterproof varnish shows no trace of the image after a time of immersion equal to the time of normal development (C. Emmermann, 1936).

In order to ascertain the normal limits of the time of development of a certain sensitive paper in a given developer, used at a definite temperature, it is necessary to find out what minimum time of development will produce the maximum black and at what stage of development the whites begin to veil or stain. These minimum and maximum times of development respectively are ascertained as follows (Dr. B. T. J. Glover, 1922).

A strip of the paper to be tested is exposed uncovered in a printing frame, at a suitable distance from a source of light, e.g. for 2, 4, 8, 16, and 32 seconds respectively, adjusting the exposure so as to produce the densest black possible. This strip should be developed for 2 minutes if it is a bromide paper, or 30 seconds if gaslight, in each case using the developer best suited to the paper. It should then be ascertained which of the exposures has produced the most intense black.

If this exposure should be either the longest or the shortest of the times given it will be necessary to repeat the test after bringing the frame nearer to or moving it farther away from the source of light. Assume, for example, that 8 seconds is the exposure which gives the densest black. A strip of paper about an inch or rather more in width should be exposed in a printing frame for the time determined, namely, 8 seconds, half of its width being covered with a length of black paper. This strip is then developed in a bath whose temperature has been noted, and

¹ In this case it is necessary to use an acid bath which will not liberate carbon dioxide from the carbonate, otherwise there is a risk of poor contact from the air-bells formed by the liberation of the gas. A saturated solution of boric acid may be used (R. Namias, 1908).

pieces about an inch long are cut or torn off at intervals, care being taken to mark on the back of each the time during which it was developed. These development times should form, preferably, a geometrical progression in a lesser ratio than that used for ascertaining the time of exposure. The following series of numbers may be taken as an example of suitable times of development in seconds—

18 25 35 50 70 100 140 200 280

the first six being appropriate for gaslight papers and the last six for bromide paper, for the purpose of this experiment.

After each piece has been developed for the given time, it is placed directly in an acid fixing bath, so as to allow the various pieces to be compared in a bright light. It will be found, in the case of bromide paper, that the black developed for say 100 seconds has less density than that developed for 140 seconds, but that there is no appreciable difference between the blacks developed for 140 and 200 seconds. From this it follows that a time of development less than 140 seconds leads to a poor black. Further, the half of each piece which has been protected from the action of the light should be perfectly clean on those pieces of which the time of development has not exceeded 200 seconds, though it may be grey and even stained yellow on the piece developed for 280 seconds. From this it follows that the time of development should be between 140 and 200, i.e. 170 seconds, or say 3 minutes. The times of development given as an example are, obviously, not those which would produce on all papers and at all temperatures the results expected. It may be necessary to repeat the test with smaller or higher numbers, but preferably following the same ratio of progression.

If examined by strong light whilst in the fixing bath or during washing, prints appear to be less dense and more contrasty (especially on mat papers) than they do after drying; it is best to judge them in a weak light.

Statistical experiments by C. M. Tuttle (1935) on a large number of prints made from amateurs' negatives on different grades of paper and with times of exposure arranged in a close geometrical progression, have shown that (at any rate in the United States) professional printers tend to produce darker prints than the customer prefers.

Precautions to be taken in placing prints in a processing bath are very similar to those already recommended for films (§ 462). In developing a number of prints together, they should be

placed successively in the dish and after an equal time in the bath should be removed in the same order. The sheets of paper should be taken in the left hand, fanned out like playing cards and taken one by one in the right hand and slid into the solution. As soon as each sheet is immersed the fingers should be passed slowly over the surface of the paper to ensure removal of air bubbles. In the case of large prints a squeegee should be used. (See § 649 for methods of treatment of prints of sizes greater than the largest dish available.)

699. Developers for Positives. While the differences in colour of the silver reduced by various developers is of very limited importance in negatives, they assume considerable importance in the case of positive prints. A developer consisting of metol and hydroquinone yields, unless special addition agents are employed, principally warm-black tones; metol without hydroquinone, a more neutral black; while diamidophenol or amidol tend to produce bluish-blacks which are unsuited for cream-tinted or chamois paper.

The formulae recommended by the different manufacturers vary considerably, even when intended for use with emulsions of the same type. Beginners will do well to follow the makers' instructions, but it may be stated that any developer suitable for one type of emulsion will develop quite satisfactorily all other emulsions of the same type. There is only one exception to this; plates or papers intended for yielding warm tones will often work more satisfactorily with one formula than with another.

Potassium bromide, the use of which is optional in developers for negatives, is a necessary constituent of developers for positive images on plates, films, or papers. The proportion of bromide which is most suited to one emulsion is not always the best for another. It is, therefore, best to make a few systematic trials to determine the most desirable proportion of bromide for a given paper.

In an industrial concern, negative developers, which have been rejected on account of an excessive concentration of bromide, may be converted into positive developers; the active constituents of the developer are estimated, the developer diluted to bring the most concentrated constituent down to the desired value, and the requisite amounts of the other chemicals dissolved in the developer to give the desired final composition (A. Haines, 1943).

According to the paper, and also according

to the developer employed, the quantity of bromide recommended by the different makers ranges from slightly less than 0.2 g to 2.5 g per litre of working developer. A series of solutions may be prepared, containing in 1 litre—

0.2 g, 0.5 g, 1.0 g, 1.5 g, and 2.5 g

of potassium bromide.

A small quantity of solution of each strength only need be prepared, and for facilitating the correct measuring of these small quantities of bromide, it may be used in the form of a 1 per cent solution. This may be measured from a dropping tube, after having ascertained how many drops represent, say, one millilitre.

A strip of the paper to be tested should be exposed to light with black paper covering half its width, the other half being uncovered. The exposure should be sufficient for the most intense black that the paper will give on development. The strip should then be cut into five pieces, which should be marked on the back and developed, each in a solution with a different proportion of bromide. The time necessary for obtaining a dense black should be noted and the action of the developer allowed to continue until either staining or veiling appears. The smallest proportion of bromide which will allow a reasonable time to elapse between full development of the black and degradation of the whites may be regarded as the correct quantity for that paper. It will be necessary to fix the test-pieces, so that they may be examined in a good light and the quality of the black correctly judged. A greenish black indicates that the proportion of bromide has probably been too great.

The presence of potassium iodide, even in very small amounts of the order of 0.05 per cent, in paper developers, considerably lowers the maximum density (P. Delmotte, 1943).

700. Stopping Development with an Acid Bath. On account of the great speed of development of positive papers, there is a risk of development continuing beyond the desired point, and even continuing irregularly, if the print be merely rinsed in plain water between development and fixing. Omission of rinsing, i.e. the transfer of the print directly from the developer to an acid fixing bath, is not to be recommended; the accumulation of developer in the fixing bath might soon discolour it to such a degree that the prints would become stained.

Most frequently the action of the developer is stopped by immersing the prints in an acid bath, where they can remain without detriment

for some time. This avoids the necessity of having to handle the developer and the fixing bath alternately; in this case, omission to rinse the hands would involve a risk of staining the prints.

This *stop bath* may be simply a weak solution of sodium bisulphite, or of any acid, or an acidified solution of alum. This latter possesses the advantage of becoming turbid as soon as the acid is saturated by the successive quantities of developer carried into it by the prints, and thus affords an automatic indication that the bath must be either re-acidified or renewed.

One litre of a bath acidified with 2 per cent acetic acid is generally sufficient for 45 sq ft of thin paper or 27 sq ft of card developed in a developer containing 3 per cent sodium carbonate.

Some papers have a tendency to acquire a very slight greenish tint after treatment with chrome-alum; in that case, chrome-alum may be replaced by ordinary alum. The acetic acid may also be replaced by any other acid which is less costly, and, in particular, by a smaller quantity of hydrochloric acid.

Strong acids should not be used at greater concentration than 1 per cent; acetic acid may be used at 2 per cent and boric acid or sodium bisulphate 5 per cent (E. Weyde, 1935).

When the stop bath contains free acid, the fixing bath should contain sufficient neutral sulphite to prevent the formation of colloidal sulphur by the acid carried in by the prints.

701. Handling of Positive Sensitive Papers in the Tropics. The precautions previously suggested for negative films and plates (§ 481) apply equally to papers. The preliminary soaking should be in a solution of sodium sulphate, or, if spirit is not costly, in water to which about 20 per cent of its volume of methylated spirit has been added; and sodium sulphate should be added to the developer. In order to avoid the use of liquid acids which involve difficulty in transport, or costly solid acids such as tartaric or citric, the stop bath may be acidified with either boric acid or sodium bisulphate.

BROMIDE PAPERS

702. Safelights. Bromide papers are of sufficiently low sensitivity to permit their manipulation in yellow, greenish-yellow, or orange light. The use of red light is not only unnecessary but distinctly undesirable, as it renders it very difficult to judge the contrast and quality of the image correctly during development.

With regard to the choice of the methods of lighting, the testing of non-actinic screens, and their preparation, reference should be made to §§ 263-7, where these matters have already been dealt with.

Paper should not become veiled after 3 minutes' exposure to the safelight since this is slightly longer than the time for which paper is exposed during normal working.

The methods of working described for papers apply equally to the same emulsions coated on opal glass.

703. Developers for Bromide Papers. The metol-hydroquinone developer recommended by the Association of French Manufacturers of Sensitized Materials (§ 466) and all other developers of similar composition are suitable for the development of silver bromide papers.¹ At a temperature of about 65°F, the image appears in 20 to 30 seconds and development is complete in about 2 minutes.

The following developer should not be prepared until required for use. It gives blue-black images and has the disadvantage of strongly staining the fingers and nails. At 65°F the image appears in 10 to 12 seconds and development is complete in about 2 minutes.

Sodium sulphite, anhydrous . . .	25 g
Diaminophenol hydrochloride (Amidol) . . .	6 g
Potassium bromide, 10 per cent solution . . .	5 ml
Water to make . . .	1000 ml

All the quick-acting developers previously given for the development of negatives, can be used for bromide papers, provided that the proportion of bromide is suitably adjusted.

704. Development. Except in the case of machine development, development is usually controlled by inspection. A number of prints are immersed successively in a dish sufficiently large and with a quantity of developer which will allow of ready handling of the prints. As soon as several prints have been immersed, they should be kept in constant motion. The lowest should be brought to the top, each print in succession, until, the image being correctly developed, the print is transferred to the acid stop bath.

In proportion as fresh prints are developed,

¹ The addition to the developer of an amount of desensitizer insufficient to stain the paper base, will prevent any risk of oxidation fog and will frequently yield cleaner images (R. Mauge, 1925) especially when prints are subsequently toned.

the developer becomes charged with increasing quantities of soluble bromide, and especially so as positive emulsions usually contain an excess of potassium bromide. Even if the temperature of the solution is constant, the speed of development falls off, and the colour of the prints tends to change progressively. The partially exhausted bath should, therefore, be replaced by a fresh bath from time to time, or, in an industrial concern, the bath should be kept at constant activity by the addition of a suitable replenisher, the formula of which may be determined experimentally (§§ 437-40).

705. In developing large prints, when it is not possible to manipulate several at once, identical copies can be obtained only by developing each for a constant time and at a constant temperature in a fresh quantity of the same developer. The once-used developer may be kept for use later in processing small prints.

Never attempt to develop a number of prints from the same negative, even in a relatively large volume of developer, if the temperature of the bath is not in equilibrium with that of the workroom, since progressive variation in temperature will cause irregularities in the prints obtained.

In order to obtain prints as perfect as possible, a trial may be made on a strip of paper from the same batch, of sufficient size to cover a highlight and shadow of the picture. This procedure cannot be too strongly recommended to the beginner, since it enables corrections to be made which might otherwise entail spoiling a large number of whole sheets of paper.

In order to ensure that prints from the same negative are as similar as possible, they should be developed together and for the same time.

706. For developing the test-piece, the Watkins *arithmetical coefficient* or "factorial" method may be used with advantage (§ 381), but the "factors" would have to be determined experimentally for this special use. The "factors" to be used may be taken as roughly about half those used for negatives with the same developer.

For the two developers mentioned in § 703 the value of the Watkins "factors" for prints on bromide paper are respectively—

Metol-hydroquinone developer . . .	× 5
Amidol developer . . .	× 10

(B. T. J. Glover, 1921.)

The total time of the development of the test piece will be, under these conditions, 5 or

10 times the interval between pouring on the developer and the appearance of the first details; and the time of development thus determined should be the same in all cases for the development of prints in the same developer.

It may appear unsound, in principle, to use (for a print, to which a certain exposure has been given) a time of development based on the time of the appearance of the most fully exposed part of the test-piece or, most frequently, of a print exposed for a different time. Experience shows, however, that the differences in the best times of development for the different parts of the test-piece are altogether negligible.

707. Local Control of Development: Brush Development. A worker who combines the qualities of a skilful technician and capable artist can produce excellent results by local development of bromide papers by means of a brush. But such methods are not in any way advisable for beginners.

The developer to be used should have no tendency to give oxidation fog, which excludes all developers containing hydroquinone, or to produce coloured oxidation products, which excludes amidol; the glycin developer given in §468 may be used if the bromide content is suitably adjusted.

Two dishes should be provided, one containing diluted developer and the other plain water.¹ There should also be a sheet of glass larger than the print, placed level on the table; a measure containing developer somewhat less diluted and thickened by the addition of glycerine, sugar or gum arabic; and several brushes of suitable sizes, according to the work in hand.

The print should be immersed in the dilute developer and transferred to plain water as soon as the image is completely visible. After rinsing, it should be placed on the sheet of glass, face upwards. The parts of the image which it is desired to increase in density are painted over with the less dilute developer by means of a brush. The print should be frequently immersed in water to avoid the edges of this local development showing too evidently. From time to time the print is again immersed in the dilute developer, and possibly, development may be completed with the print on the glass plate; any parts which are required to remain light are

painted over with a weak solution of bisulphite which prevents their further development.

It should be noted that since prints prepared in this way are not developed to the same gamma all over, subsequent sulphide toning may produce a variation in tone which is not acceptable.

The development of very large prints can be carried out, in the absence of very large dishes, in the following manner. The print should be thoroughly wetted and laid on a flat support of suitable size, e.g. a bench covered with rubber sheeting. Developer, diluted with an equal volume of water, to render its action slower, should be quickly spread over its surface by means of a sponge or a large brush.

POSITIVE TRANSPARENCIES (BLACK TONE) ON PLATES AND FILMS

708. General Considerations. Transparency emulsions being distinctly faster than those for bromide papers, all manipulations should be carried out in either orange-red or green light. Conditions of development (composition and concentration of developer, degree of agitation, etc.) have a considerable effect on the characteristic curve and particularly on the toe of the curve; the point where the straight-line portion of the curve commences may be displaced considerably and the length of this part of the curve may be shorter or longer thus affecting the tone-rendering. Analogous variations also occur in the shoulder of the curve, but this has little effect on the prints since the densities involved are usually greater than the highest densities used in practice.

The maximum density of a transparency to be used for projection rarely exceeds 2.5. Thus the effective brightness range may be defined as the difference of intensities which give respectively a density of 2.5 and the lowest density which can be distinguished from the bare glass. For the same plate or film this range decreases in proportion as it is developed to a higher gamma (L. Lobel, 1928), thus passing from about 1,000 to 30 on ordinary transparency emulsions (the density range of the negative passing from 3.2 to 1.5) and from about 13 to 3 (density ranges of the negatives 1.2 and 0.5) on a high-contrast negative emulsion used as a transparency.

The possibility of lowering contrast by means of an auxiliary uniform exposure is of little interest in the case of transparencies which are best developed separately, but is useful in

¹ The method of development consisting in starting development in a strong bath, and then allowing it to continue in plain water in order to decrease exaggerated contrasts (§ 389), is applicable to most bromide papers.

cinematography where all the scenes have to be developed under standard conditions (E. A. Weaver, 1925).

When the negative possesses strong contrasts, or when development of the transparency is prolonged in order to obtain great contrast, it is best to guard against halation (§ 212) by applying to the back of the plate an anti-halo paste or adhesive (§§ 252 and 253). There is no need for this precaution, as a rule, when printing on films.

In copying on plates, care should be taken to minimize faults due to poor contact, which may be caused by inevitable faults in the flatness of the glass; the use of diffuse illumination should be avoided for this reason.

709. Excepting for the reproduction of diagrams of drawings in black-and-white, the whites of a subject should never be represented by bare glass, unless they represent a direct source of light or its reflection.

On transparencies to be used as intermediate negatives for the production of duplicates, all densities should be on the straight-line portion of the characteristic curve, which means that the high-lights should have a density of about 0.5.

The beginner will avoid spoiling a number of plates if he makes systematic tests to ascertain the correct exposure in the manner already described for prints on paper. These tests should be made on strips cut from a plate, or, in the absence of a diamond or other glass-cutter, on the smallest size of plate which can be obtained. These should have the same emulsion number, if possible. This determination of the time of exposure is specially necessary when printing either from very thin or very vigorous negatives.

The examination of the finished transparency should always be made under the normal conditions of its ultimate presentation. Only by very long experience is it possible to judge, from the transparency held in the hand before a well-lighted white diffuser, the effect which it will produce when projected on the screen.

710. Development of Black-tone Transparencies. The determination of the time development by the Watkins method (§ 381) is not applicable to transparencies for projection. It is, in fact, the light tones of the image which are the most important; the time of the appearance of the shadows cannot be relied upon exclusively as a guide. The use of this method for the development of prints on bromide paper (§ 706) is admissible only because the image of the light tones possesses the strength desired at the same

time as the shadows attain their maximum density, provided that a paper is used of which the gradation is suited to the contrast of the negative. This does not apply in the case of transparencies when the same emulsion may be used with negatives of very different character.

Development must be judged by inspection (or in the case of machine development, by pre-determining the optimum development time in a developer which is maintained at constant activity); it is not necessary to examine the plate by transmitted light until the light details are visible by reflection.

The quality of a lantern slide is best judged by projection. For a provisional examination it may be held at about 4 in. from an opal flashed glass uniformly lit by a lamp of about 60 watts.

Most methods of obtaining coloured images by toning also act as intensifiers. It is therefore necessary to curtail the development of transparencies which are to be toned; in order to obtain full details in the light tones under these conditions, a somewhat greater degree of exposure should be given.

The equipment and methods of working are the same as those already described for negatives on plates or films.

711. All developers which are used for the development of negative emulsions or bromide papers may be used for the development of transparencies if the concentration of bromide is suitably adjusted, but in practice only metol and hydroquinone developers are used. Developers containing a high concentration of sulphite, should, however, be avoided, since these tend to promote the production of dichroic fog (§ 387) owing to the fact that the finer grains of silver bromide are more easily soluble than the larger grains present in fast negative emulsions.

The developer given below is an example of a developer used for cine-positive film and the replenisher solution (§ 438) which is used to maintain the developer at a constant activity (Agfa formula No. 20).

	Developer	Replenisher
Metol (Elon, Rhodol, etc.)	2 g	4 g
Sodium sulphite, anhydrous	25 g	25 g
Hydroquinone	4 g	10 g
Sodium carbonate, anhydrous	18.5 g	45 g
Potassium bromide	2 g	—
Water to make	1000 ml	1000 ml

In an installation using 1,000 litres of developer (tank and reservoir) the activity was kept constant for 2 months during which time 120,000 metres of 35-mm film were developed by the addition of 1,050 litres of replenisher per 100

metres of film processed. The positive film which was introduced dry into the developer, removed about 5 ml of developer per metre and a further volume of used developer was bled away to keep the level constant in the reservoir.

712. Preparation of Duplicates. Duplicates or copy negatives are made from specially prepared transparencies and this operation has become of considerable importance in cinematography, release prints never being made from original negatives but always from duplicate negatives. A perfect duplicate should yield identical prints to those obtained from the original negative in the matter of tone rendering, graininess, and resolving power.

The first of these conditions is met by making the intermediate transparency (or master positive) on a sensitive material having a long straight-line portion to its characteristic curve. The exposure is adjusted so that the densities of the intermediate positive fall on the straight-line portion of the characteristic curve and this implies on the special motion picture films a minimum density of about 0.5. A transparency which is suitable for viewing and in which the high-lights are in the under-exposed region, gives unacceptable duplicates in which the half-tones are merged with the pure whites.

The correct reproduction of sound on motion picture film imposes the condition that the negatives should be developed to a gamma of about 0.65 and the positives to a gamma of about 2.0, and it is logical to adopt the same values for both duplicate negatives and master positives.

Special films for master positives were formerly coated on a bluish-lavender coloured base in order to avoid confusion with ordinary positive film and in the language of the work-room these were often termed "lavender prints." However, the modern fine-grain duplicating materials which give excellent quality duplicates, are as different in image colour to normal materials as to render the use of coloured bases obsolete.

These particular values of gamma are not essential in ordinary photography and it is thus possible to use normal positive materials, the matrix and duplicate both being developed to a gamma of 1.0. In this way it is possible to avoid the use of sensitometric methods.

By superimposing on the negative a positive which has been copied from it (or vice versa) a uniform density will be obtained if both have been developed to a gamma of 1.0. The

effect of the copy predominates if it has been developed to a gamma greater than unity or of the original if it has been developed to a gamma of less than unity. The superposition of a negative and a positive from another negative taken from the same position, the images being developed to the same contrast, may be used to detect small differences in a complicated assembly of objects, the objects which have been displaced showing up as marks on the uniform density. (M. B. Hodgson and R. B. Wilsey, 1917).

In order to avoid an increase in graininess in making successive copies, it is necessary to use films for both master and duplicate which have much finer grain than the original negative. This condition is not, however, sufficient in itself. The Eberhard effect (§ 397) which exaggerates the contrast between adjacent areas, of different density, tends to increase progressively the graininess of successive copies (Y. N. Burkin, 1939) if the developer is not vigorously agitated during each development.

It is never possible to avoid a certain loss of resolving power due on one hand to irradiation, (§ 212) which can be reduced by a yellow dye in the emulsion layer, and on the other hand to faults in contact between the sensitive materials during copying. Faults in contact may be reduced firstly by using almost point sources of illumination such as arcs between balls of tungsten (called Pointolite lamps) and secondly by using high pressure such as is afforded by the use of vacuum printing frames (§ 610). In the absence of such apparatus the making of contact prints should be avoided, sharper results being obtained by using the negative or master as a transparency. Under these conditions, each reproduction tends to lower the contrast due to internal reflections, the greatest effect being in the lower densities.

When working with plates, precautions should be taken at every stage of the operations to avoid halation.

Experience has shown that by making systematic preliminary trials, or better still by sensitometric control of the operations (L. Lobel and H. Schneeberge, 1925) it is possible to obtain duplicate negatives which are better suited than the original negative for the production of copies by a given procedure, since the density range of the duplicate may have any desired value greater or less than the original negative.

713. By making use of the properties of polarized light, it is possible to obtain a vigorous medium negative directly from a weak negative

(§ 122). The silver of the image is converted to a colourless translucent salt, for example the ferrocyanide (§ 751) and illuminated by polarized light. The objective of the viewing apparatus or enlarger is furnished with a polarizer, the directions of the polarizing planes being crossed. The image then appears as contrasty positive, the light not diffused by the image being totally extinguished by the second polarizer. Only the light which has been depolarized by diffusion in the translucent substance can pass the latter so that the intensity is greater the greater the image density at the point considered. The contrast may be lowered at will by turning more or less one of the polarizers which is extinguishing the non-diffused light (C. H. Smith, 1941).

BLACK-TONE CHLORIDE PAPERS

714. General Recommendations. In well-equipped laboratories and particularly in professional or industrial laboratories, slow silver-chloride papers are handled in plenty of bright yellow light; the rapid papers used for enlargement and obtained by the incorporation of sensitizers whose action extends into the blue-violet (§ 218) can only be handled in orange light.

One of the factors which have tended most to popularize the use of these papers among amateur photographers is the fact that they may be worked in safety without a dark-room. Any domestic room may be used simply by waiting until the evening and not working too near a light. An amateur can, therefore, make his photographic prints during the evening, in a sitting-room, in comfortable warmth, very different from the conditions in an improvised darkroom. For example, a screen may be placed near the table on which the printing frames are loaded and the exposed prints are developed, in such a manner as to shield the table from the direct light from the lamp, all the manipulations being carried out by the light diffused from the ceiling and walls. It is, however, far preferable to use yellow light, which allows a much stronger illumination without any risk of fogging. For this, a light wooden frame may be used, covered with a translucent yellow paper, and made in such a form that it will stand upright on the table. Half the table can then be used for exposing the prints, preferably by means of a portable lamp, the other part being devoted to the working. The

sensitive paper should be kept in a drawer in the table until required, so as to be protected from the general diffused light.

715. Developers for Silver-chloride Papers. The ready solubility of silver chloride in sulphite solutions, which is favoured by its extremely fine state of sub-division, results on development in a developer rich in sulphite in the formation of a yellow or brown fog, which is of the same nature as dichroic fog (§ 387). Thus, although it is always possible to use a developer recommended for chloride papers with bromide papers, the inverse is not always true. Special developers for chloride papers often do not keep so well as negative developers.

The presence of soluble bromide in the developer is essential; this bromide transforms part of the silver chloride of the emulsion into silver bromide and the bromide concentration progressively decreases as the developer becomes charged with inactive chloride. In order to maintain constant activity in a developer for chloride papers, the replenisher solution must therefore contain bromide.

The concentration of the developer should always be such that development is very rapid, because even in a developer of low sulphite content and relatively high bromide content which depresses the solubility of silver chloride in the sulphite, a somewhat prolonged development always leads to the production of yellow fog.

It has sometimes been recommended that soft or medium papers should be developed in a developer of less than half the concentration of that used for contrasty papers, the development time being doubled. This practice has neither advantage or disadvantage, but the developer should not be diluted for contrasty papers.

The following metol-hydroquinone developer is well suited for these papers and may be easily prepared at double strength and diluted with an equal volume of water as required. In full well-stoppered bottles the concentrated solution will keep for more than 3 months.

Metol	2 g
Sodium sulphite, anhydrous	25 g
Hydroquinone	6 g
Sodium carbonate, anhydrous	35 g
Potassium bromide	1 g
Water to make	1000 ml

716. Production of Blue Tones. It has been stated many times since the introduction of hot glazing machines in developing and printing works, that blue-toned images do not suffer the same loss of contrast generally obtained

with neutral black images. Many experimentalists have studied this phenomenon since 1932 in order to try and find the most practical and certain methods of obtaining blue tones, and it has become necessary to regard blue tones as a criterion of good quality prints.

It has been shown that images in blue-black tones are formed by large silver grains, with a covering power a little less than the very small grains giving neutral images, but which do not, like the latter, tend to agglomerate in a mass when the damp image is warmed to a temperature of about 100°C.

The formation of blue-black tones is favoured by a lowering of the bromide concentration, but this is not to be recommended since this increases the risk of obtaining yellow fog. Amidol developers (§ 469) give a slightly bluish image without the addition of any other agent. The blue tones which are desired may be obtained by the use of various addition agents, which may either be incorporated in the emulsion or anti-abrasion coating, or added to the developer. The action of these addition agents is impeded by the presence in the developer of hypo (thiosulphate). Some very complete studies of these addition agents have been published by G. Schwarz in 1936 and 1939.

The compounds giving rise to blue tones, which are nearly all only slightly soluble, may be divided into three groups—

1. Heterocyclic bases capable of forming complexes with silver halides: benzotriazole, 6-nitrobenzimidazole and their salts used at concentrations from 0.01 to 0.05 per cent, salts of quinoline or quinone (quinoline itself, which is very efficacious at concentrations less than 0.05 per cent, cannot be used because of its very disagreeable odour, but certain of its derivatives, especially the alkaline oxyquinoline sulphonates, are just as useful without giving this inconvenience).

2. Iodonium salts, for example the nitrate of diphenyl iodonium.

3. Sulphur bodies, such as rhodamine and its derivatives.

It should be noted that most of these compounds are also anti-fogging agents (§ 386); most of them are not normal commercial products.

Blue-black tones may also be obtained either by an addition to the developer of from 1 to 1.5 ml per litre of a 5 per cent solution of potassium thiocyanate or by a very incomplete

after-toning with gold (§ 742) or selenium (§ 743). Images treated in this way have the same stability on hot drying, as images directly developed to a blue-black tone (G. Schwarz, 1932).

717. Development. The development of silver chloride papers is too rapid to allow of the use of the Watkins method described for bromide papers. The instructions issued by the manufacturers nearly always recommend a normal time of development and this should be followed. The time of development in the developer formulated above (§ 715) for most papers of this type should be between 20 and 40 seconds at 65°F or between 30 and 60 seconds at 55°F (B. T. J. Glover, 1924). Thirty seconds may be adopted as the standard time of development over this range of temperatures. The exposure time should be determined by means of strips as already described in § 694.

A developer which is too warm usually gives a blue-black tone but with grey and yellow fog. A developer which is too cold will not give a vigorous image.

A developer which has a low carbonate content, or which is too dilute or exhausted, sometimes gives dirty whites if the paper has not been stored in a dry atmosphere, a fact which may cause beginners to think that the paper has not been uniformly coated with emulsion. Old papers, (out of date) sometimes give fog in the margins, if developed in developer containing insufficient bromide. Because of the extremely rapid rate of development it is almost essential to use an acid stop bath in order to obtain consistent results; alternatively, the prints should be agitated vigorously during their first few seconds in the acid fixing bath.

WARM-TONE TRANSPARENCIES

718. General Considerations. Warm-tone lantern plates are very thinly coated with an almost transparent layer of very fine-grained silver bromide or chlorobromide emulsion (unripened), the grain size having as large an effect as the nature of sensitive halide.

These emulsion, which are very slow, may be handled in a room well-illuminated with yellow light; but visual control of development is practically impossible since the image is hardly visible in this light.

When developed in a well bromided developer containing a silver halide solvent (sodium sulphite, ammonium salts, etc.) they give a brightly coloured image of colloidal silver (yellow, red,

or violet according to the size of the ultra-microscopical particles) mixed in different proportions with the microscopical particles of reduced black silver. (Some black-tone emulsions will also give warm tones when developed in developers with a strong content of ammonium salts but the tints obtained are never so clean.)

During development, because of the progressive increase in size of the reduced silver particles, the image passes through a series of colours, which when observed in a white light after fixing, washing, and drying, are as follows.

Yellow, orange, red, brown, sepia, greenish-black, black. This colour series is independent of the exposure and light source. In any given developer (at the same temperature and concentration) the same colours are always obtained on similar plates after the same times of development (A. Joderus, 1896). In developers which differ somewhat (due to variations in purity of the constituents, errors in weighing or dilution, or differences in temperature) the same colour is always obtained at the point when equal gamma is reached (S. H. Wratten, 1910). It is only for convenience in working—i.e. for passing more or less rapidly from one colour to another—that it is recommended to use developers differently constituted, or differently diluted, for obtaining a given tone. However, when developing in a very dilute developer, on certain emulsions, it is not possible to obtain tones beyond red or brown however much development is prolonged, although the gamma continues to increase, but the colours obtained are brighter. (L. Lobel and M. Dubois, 1929). Violet is not always obtained when developers are used which do not contain ammonia or ammonium salts.

719. It will be seen from the fact that the colour depends essentially on the contrast of the developed image that negatives of different contrast are not equally suitable for obtaining images of a given colour. Assuming, as has already been done for black-tone transparencies, that the density range should be limited to 2.5 (§ 708), then it has been found (L. Lobel and M. Dubois, 1929) that the intensity ranges and corresponding negative density ranges, which will give the various colours on one particular make of warm-tone lantern plate, are as follows. The values differ a little according to the make of plate but they always follow the same order.

Colour of the Image	Red-brown	Sepia	Greenish-black	Black
Intensity range	2.5 : 1	25 : 1	16 : 1	10 : 1
Density range of the negative	2.1	1.4	1.8	1.1

The maximum density of a violet-red image is always below 2.0; the intensity range is almost the same as for a red-brown image but contrast is considerably lower.

Because of the differences between plates of different makes, one make may be more suitable than another if one wishes to obtain a given colour from a given negative. With another negative of different character the make rejected in the first case may be preferable. Although it is very unlikely, the photographer may not have any preference for a particular colour. In such cases warm-tone plates may be used with negatives of very different character by giving a suitable exposure in each case, or, when printing from a particular negative, a very great latitude in exposure may be allowed. It is very simple to obtain a result on these plates but it is not so easy for a beginner to obtain a perfect image in the desired colour.

More varied and more transparent tones may be obtained with more speed and certainty by dyeing mordanted transparencies which have been developed to give a black image.

720. **Exposure.** The statement that the colour of the image is independent of the exposure, under given conditions of illumination, does not imply that the exposure should be the same whatever may be the colour desired.

Under the conditions of development determined upon, the density of a certain part of the image is greater in proportion as the exposure time has been greater. For a given degree of development, the image may not appear in those parts of the subject which form the densest parts of the negative unless the exposure has been greater than a certain minimum—a minimum which varies with the time of the development on account of the regression of the inertia (§ 393) in a developer rich in bromide, as is usual in developers for warm tones.

The exposure must consequently be prolonged in proportion to the extent to which development is shortened for tones more or less red, so that details in the lights may appear with sufficient strength before development is stopped.

According to the plate used, the time of exposure necessary for obtaining red tones will be from 10 to 20 times that which is necessary for black tones, the same illumination being used. It will easily be seen that since development is limited to a small fraction of each grain, this must be compensated for by an over-exposure which renders developable a much greater number of grains. No general rule can be given,

and, for a first trial, it is best to follow the instructions given by the makers of the plates. These preliminary tests can be made on pieces cut from one of the plates, the determination of the time of exposure being carried out under the conditions already described (§ 694). The same test will furnish experimental proof of the fact that the colour of the image is independent of the time of exposure. The parts of the test piece, though exposed for different times, will all be identical in colour after development, and will differ from each other only in the density of the image and the rendering of the details in the lights.

721. Warm-tone Development. It is almost impossible to judge the colour and the density of the image properly in coloured light during development. A yellow light weakens considerably the contrasts of a sepia or red-chalk image, while a green light exaggerates them. In addition, both the colour and the density of an image change considerably on drying, as may be easily ascertained by examining a plate which is partially dry. An image which is pale yellow when wet can become an intense red-chalk after drying. These reversible variations are due to the increase in refractive power of the gelatine as it gradually dries (§ 650).

Thus, for uniform results as regards colour, plates should always be developed in solutions identical in composition, and used at the same temperature and for the same time, or else the times of development should be worked out by the Watkins system. Although, as has been previously shown (§ 717), this method is inapplicable in the case of transparencies of black tone, for which development is done by judging the light tones, its use is perfectly sound in the case of plates of warm tones when a certain colour is desired since it has been shown that the colour of the image depends essentially on the value of the contrast factor.

When transparencies are intended for projection, it is well to suspend all judgment until they are seen on the screen. The appearance of the projected image is frequently very different from that which it presents when simply held up to the light.

A transparency which is considered defective in colour may be improved by gold toning (§ 742). The tones tend to become purple, but the image loses nothing of its transparent quality.

722. A widespread belief exists that hydroquinone is the only developer which can be

satisfactorily employed for warm tones. Many other developers give just as good results but the presence of metol or para-aminophenol in a developer, even in small quantities, often renders it difficult to obtain suitable warm tones.

The best results are obtained by following the manufacturer's instructions but formulae for developers are here given which are suitable for a large variety of commercial plates—

Hydroquinone—

Sodium sulphite, anhydrous	35 g
Hydroquinone	10 g
Sodium carbonate, anhydrous	30 g
Ammonium bromide	2 g
Potassium bromide	3 g
Water to make	1000 ml

Dilute with 1 to 10 times the volume of water, the greatest dilution being best for obtaining red tones.

Glycin (Vannier, 1920)—

Sodium sulphite, anhydrous	50 g
Sodium carbonate, anhydrous	40 g
Glycin	20 g
Potassium bromide	15 g
Water to make	1000 ml

For use, to be diluted from 5 to 20 times, according to the colour desired.

Acid Amidol (G. Balagny, 1906)—

Sodium sulphite, anhydrous	5 g
Amidol	2.5 g
Sodium bisulphite, lye (35%)	40 ml
Ammonium bromide	5 g
Water to make	1000 ml

Only sufficient for immediate use should be prepared. The action is very slow, and it is not necessary to dilute the solution for obtaining red tones.

WARM-TONE CHLORO-BROMIDE PAPERS

723. General Considerations. Chloro-bromide papers which are low in chloride or bromide content behave respectively as bromide or chloride papers. It is only necessary to consider here chloro-bromide papers which are specially destined for the direct production of warm tones.

The work-room may be illuminated with yellow light but this should be less bright than may be used for chloride papers. In order to control the results, it is necessary to examine the prints by white light as soon as possible after fixation. It is therefore advantageous to be able to illuminate the dish directly by means of a bluish bulb (daylight lamp) or by a lamp

with bluish glass. Usually only the range of tones from neutral black passing through sepia to warm brown are required and it is not proposed to describe the methods of obtaining a range of colours similar to those described for warm-tone transparencies, especially since these tones may be obtained by toning.

These papers are much used by portrait workers since they give images comparable in quality to those which may be obtained on chloride papers without requiring such intense illumination in the enlarger, and avoid the necessity of toning in order to obtain the warm tones which are so much appreciated for this type of work.

The mechanism of obtaining warm tones has already been described for transparencies (§ 718) but since many of these papers contain a small proportion of large grains which develop to a black, they will only give degraded tones. Grains of a suitable size for giving warm tones are only produced by relatively slow development in a strongly bromided developer, although an excess of bromide should be avoided since this would retard development without having any useful effect.

The visual contrast of a brown or sepia image is greater than that of a black image on the same paper and therefore requires a slightly softer negative. The sequence of intermediate tones is not the same on all papers; on some it is the same as for transparencies but on others the tones pass with increasing development through the range red-violet, brick-red, sepia, warm brown, warm black, blue-black.

The warmest tones are again obtained by over-exposure and development to low gamma. If it is not essential to obtain a pre-determined image colour, these papers may be used for negatives of varying character or will allow considerable exposure latitude with a given negative.

These papers are usually only supplied in one contrast grade.

724. Methods of Working. When commencing work with a paper of this type it is best to determine the optimum exposure by the step-wedge strip method (§ 694), each experimental strip being developed for a different time; for example using three or four times in an arithmetic series from 2 to 6 minutes (§ 381). A comparison of the step-wedges after fixing, washing, and drying will at once indicate the best exposure and development times to give various tones, from which may be chosen the one best suited for the subject and character of the negative.

Although some papers for warm tones may only give the desired results when they are used with the developer specified by the manufacturers, most will work perfectly with the following developer (B. T. J. Glover, 1924)—

Metol-hydroquinone Developer for Warm Tones.

Metol	2 g
Sodium sulphite, anhydrous	25 g
Hydroquinone	8 g
Sodium carbonate, anhydrous	18 g
Potassium bromide	2 g
Water to make	1000 ml

For use, this solution should be mixed with an equal volume of water.

A warm black tone is obtained by developing for a total time, according to the particular paper in use, ranging from 4 to 6 times the time of the appearance of the first details of the image. A brown tone is obtained by developing for times ranging from 2½ to 4 times the time taken for the first appearance of the image. These times are best found by actual test of the material.

The presence in the developer of energetic silver solvents (such as hypo or ammonia) or high bromide content, will correct the tendency for stale papers to give blacker tones than new papers (A. Steyman, 1939).

FIXATION, INTENSIFICATION AND REDUCTION OF POSITIVES

725. Fixing and Hardening Papers. The chemistry and mechanism of fixation are the same as for negatives (§§ 487-91) with the peculiarity already referred to that the paper fibres and baryta coating irreversibly absorb a small amount of hypo and its complex silver salt (§ 507). The quantity thus retained, which escapes the washing process, is greater in proportion as the fixing bath is more acid, as the time the paper remains in the bath increases and as the fixing bath is more concentrated and contains more silver salts (E. Weyde, 1935). The amount of the adsorbed salts may be decreased by immersing the rinsed prints from the fixing bath for about 1 minute in a 1 per cent solution (approx.) of sodium carbonate, the solution being renewed before it becomes neutralized by acid carried in from the acid fixing bath. Perfect stability of prints on paper can only be assured by treatment with hydrogen peroxide and ammonia (§ 513).

726. The fixing of prints is preferably carried out in deep dishes containing fixing solution of a depth of at least 2 in. A paddle of hard wood

should be provided, of broad shape, and with the sharp edges rounded first with a rasp and then with glass-paper. The prints can then be completely immersed without having to put the fingers in the solution.

Certain papers float on a solution which contains 25 per cent of hypo, an average strength for fixing baths for negatives. In such cases it is necessary to dilute the bath sufficiently to reduce its density until the prints tend to sink to the bottom of the dish. It is well known that silver images are reduced during fixing by the free access of atmospheric oxygen to their surfaces (§ 489). Moreover, parts of the prints protruding from the solution may continue to develop, if they have not been through an acid bath between development and fixing; or yellow staining of the same character as dichroic fog may result (§ 525). Similar defects may arise with prints fixed face downwards if air-bubbles have been imprisoned under them.

Whenever possible, fixing should be done in two successive baths (§ 496).

Prints should always be introduced into the bath singly, and moved every now and then, the lowest print being brought to the top, and so with all in succession. The prints should also be taken from the bath one by one to be transferred either to the second fixing solution or to the first washing water.

In commercial establishments dealing with large numbers of small prints, the prints are sometimes thrown on to an endless belt driven by a small electric motor, which conveys them under a series of water sprays before immersing them in the fixing bath.

With bromide papers, an increase of contrast is sometimes noticed when the prints are placed in the fixing bath, either neutral or acid.

The time of fixation in a fresh bath of 20 per cent hypo is from 1 to 2 minutes and prints should not be left longer than about 5 minutes in each bath. In the case of warm-tone prints this time can with advantage be reduced.

Fixing baths which have previously been used for negatives should not be used for papers since they will contain iodide which will greatly reduce the rate of fixation.

Control of the degree of exhaustion of fixing baths, their regeneration and methods of silver recovery have been described in connexion with negative fixation (§§ 500-6).

727. Suitable fixing bath formulae are given in § 499; these may be diluted if necessary (§ 726).

The gelatine is usually hardened sufficiently during manufacture to allow of drying or glazing at a relatively high temperature. Those papers which do not carry a hardened emulsion or which one has reason to suppose will require hardening, may be fixed in a bath containing alum. They may also be hardened after washing (and finally after toning) by treatment for 5 to 10 minutes in the following bath—

Sodium sulphite, anhydrous . . .	12.5 g
Glacial acetic acid . . .	5 g
Potassium aluminium alum . . .	35 g
Borax . . .	7.5 g
Water to make . . .	1000 ml

To prepare the bath, dissolve the chemicals separately in warm water and after cooling, mix the solutions in the order given with continuous agitation.

The use of chrome-alum baths should be avoided as these will irreversibly stain the gelatine green when it is hardened; as already indicated formalin should also not be used.

In fixing images on sensitized aluminium, if the surface of the aluminium has been protected by anodic oxidation, it is recommended that about 25 g per litre of ammonium nitrate be dissolved in the fixer; this will prevent the formation of black spots, which would otherwise be formed in a used fixer at the points where discontinuity of the anodizing occurs (C. H. Mitson and G. W. W. Stevens, 1942).

728. **Intensification.** The intensification of a transparency, or a print on paper, allows of increasing the strength of a print when development has yielded insufficient contrast, or of remedying an unpleasant tone.

If a print on an opaque support already contains black tones, intensification will cause a loss of details in the shadows, since these will be brought up to the same density as the original blacks which cannot be intensified.

Most of the toning processes described in the succeeding paragraphs strengthen the image, and can be used for intensifying when a black tone is not essential.

Among the various methods of intensification described for negatives, the only one which is suitable for strengthening prints on paper or transparencies is the chromium intensifier (§ 550). Immersing the bleached print for a few seconds in a solution of sodium carbonate, of about 5 per cent strength, greatly facilitates the elimination of the bichromate. Warm tones may be avoided on images intensified in this way, particularly in the case of transparencies, by

an addition to the developer of one of the substances recommended for obtaining bluish tones (§ 417) for example 0.01 per cent of 6-nitrobenzimidazole nitrate (H. A. Muller and J. I. Crabtree, 1943). The use of mercury intensifiers should be especially avoided; they spoil the transparency of the shadows, increase the graininess to a disagreeable degree, and do not give stable images.

729. Reduction. The various reducers given for negatives (§§ 554-62) can be used equally for transparencies, under the same conditions and by observing the same precautions. The results, however, are frequently very different because of the much smaller grain size involved. It is also practicable to reduce exaggerated contrasts in a transparency by bleaching it in a mixture of potassium ferricyanide and sodium chloride (common salt) or potassium bromide. After washing, it should be exposed to light. The result is a brown image if chloride is used, or grey, if bromide is employed. After darkening, the excess of chloride or bromide may be removed by fixing. The image may also be treated in a mixture of ferricyanide and potassium iodide; the image, consisting of silver iodide, is insensitive to light, and is light yellow when seen by reflected light and brown by transmitted light.

A very complete study of the reduction of prints made on the different types of development papers has been carried out by L. A. Jones and C. E. Fawkes (1921). It contains a number of photometric measurements of prints before and after reduction, and shows that all reducers do not act in the same manner on the comparatively coarse-grain images of bromide prints and on the fine-grain images of gaslight and chloro-bromide prints.

An acidified solution of permanganate, which acts as a surface reducer on negatives reduces proportionately all the densities on almost all papers, and therefore best compensates for over-development. It should be used at 10 times the dilution of that given in § 557. Before the final washing, prints should be decolorized in a dilute solution of sodium bisulphite. This reducer is also applicable to sulphided images.

For reducing the light tones without producing any appreciable effect on the heavy deposits of the image, Farmer's reducer may be used very dilute (§ 556), or, alternatively, a mixture of iodine and cyanide. The latter is preferable, as it leaves no trace after reduction, while ferricyanide frequently leaves a yellow

coloration which, however, will usually disappear in a few minutes in a new acid fixing bath.

Formulae for these two reducers are here given. They are practically equivalent, and may be used with advantage for prints taken from negatives with insufficient contrast for the paper employed when the exposure has been chosen for obtaining the maximum black. Each of these reducers should be prepared in a small quantity only, and at the time of using; their activity disappears in a few minutes.

Farmer's Reducer—

Hypo., 10% solution	250 ml
Potassium ferricyanide, 1% solution	250 ml
Water to make	1000 ml

Iodine and Cyanide Reducer—

Iodine, 1% solution	60 ml
Sodium cyanide, 1% solution	10 ml
Water to make	1000 ml

Cyanides are most violent poisons, even in very small quantities, and are supplied only for commercial use.

Iodine is insoluble in water but dissolves very readily in concentrated solutions of potassium iodide. It forms a dark brown liquid which can be diluted as much as required. To prepare the *iodine solution* above mentioned 6 g of potassium iodide should be dissolved in about 30 ml of water; 3 g of iodine should be added and by shaking the solution from time to time the iodine will be completely dissolved in about an hour. Iodine being very volatile, the solution should not be heated. When it is completely dissolved, sufficient water is added to bring the total volume up to 300 ml. Iodine and its solutions will attack cork stoppers.

One or other of these solutions is generally used for clearing the margins of prints which are slightly veiled or defaced by stress or abrasion marks (§ 692); for the complete removal of an image which has been used as the basis of a line drawing in waterproof ink; also for local reduction with a brush.

Reduction with a brush is much more easily carried out with an alcoholic solution on the dry print. A mixture of equal parts of the following two solutions should be used (T. H. Greenall, 1926), diluted, if required, with an equal quantity of methylated spirit for working on light tones—

Iodine flakes	4 g
Methylated spirit	100 ml
Thiocarbamide (thiourea)	8 g
Water	100 ml

As soon as the image has been treated with a water-colour brush moistened with the reducer, a larger brush thoroughly saturated with methylated spirit is passed over it, and the spirit remaining on the print blotted off at once. This sequence of operations is repeated until the desired effect is obtained. When the reduction is completed, the print should be placed *without intermediate rinsing* in a fixing bath and then washed in the usual manner. Rinsing before fixing induces risk of staining by silver sulphide, on account of the decomposition in water of the complex formed by the thiocarbamide and the silver salt.

The same result may be obtained more economically by means of a solution containing .5 per cent of cupric chloride and 1 per cent hydrochloric acid; the image bleached in this solution is rinsed, fixed in a fresh bath, and washed.

For reducing the deep shadows of a print without appreciably weakening the details in the light tones, the ammonium persulphate reducer should be employed (§ 560). To avoid the deepest shadows being reduced to such an extent that they possess less strength than the intermediate tones, it is necessary, with some very fine-grain papers, to add a small quantity of a chloride to this reducer. Only the quantity required for immediate use should be prepared.

Persulphate Reducer for Prints on Development Papers —

Ammonium persulphate	25 g
Sulphuric acid, 1% solution	30 ml
Sodium chloride (common salt), 1% solution	25 ml
Water, to make	1000 ml

TONE CONTROL AND THE PRODUCTION OF SPECIAL EFFECTS

730. Compression of Intermediate Tone Values.

One of the essential criteria of the artistic perfection of a print is that the high-lights and shadows must agree with those seen when looking at the original subject, the intermediate tones being of secondary importance. A comparison of photometric measurements on some engravings of the "Chalcographie du Louvre" and on photographs of the corresponding pictures has led F. G. Maurer (1923) to conclude that the normal reproduction curve in monochrome photography should have a horizontal or very slightly rising portion in the middle regions whilst the slope at the extremities of the curve should be in the neighbourhood of unity. The masterpieces of Rembrandt are

cited as examples showing the importance accorded by the artist to the high-lights and shadows, to the detriment of the middle tones.

Many photographs have been made in the past which have conformed more or less intuitively with this rule for the reproduction of subjects of high brightness range, for example, by combination of two negatives, one exposed to give the best reproduction of the high-lights and the other exposed for the shadows. Another method involves the superimposition of two positive images printed from the same negative which has very different extreme densities, one of the copies giving a correct representation of the high-lights and the other of the shadows.

By a suitable choice of the two exposures such combinations of positive images have been used very profitably in the pigment processes such as gum bichromate or bromoil transfer, which lend themselves to the creation or the transfer of a number of images on to the same support.

A method patented by A. Person in 1930 was unnoticed at that time, but an exhibition of prints made by the method was organized successively in different countries (1935-6) in order to obtain publicity. This brought it to the attention of the public and caused a number of variations to be suggested which gave results very little different from the original method.

731. The Person process consists in making a negative with a density range so great that it is not possible to print it even on the softest paper available. From this an over-exposed positive transparency is made which gives a complete record of the high-lights, then from this a duplicate negative is made, giving a short exposure on a very contrasty emulsion. The final print is then made by contact or enlargement, partly from the original negative and partly from the duplicate negative.

The results of sensitometric tests on this method (H. G. Wandelt, 1936) are shown in Fig. 41.5: the abscissae represent the densities of the sensitometer screen (or step wedge) which corresponds with the original negative (densities from 0. to 2.4) and the ordinates the densities of the paper copy. Curve *A* represents a copy obtained from the duplicate negative for modelling the high-lights and the curves *BB'* copies obtained from the original negative using two different exposures (greater for *B* than for *B'*). The curve *AC* in which each of the ordinates is the sum of the ordinates of curves *A* and *B* represents the print which would be

obtained by exposing successively under the two negatives and which separately would have given prints *A* and *B*. Similarly curve *AC'* represents the print which would be obtained by a combination of the partial exposures *A* and *B'*.

It will be seen that in the example chosen, all negative densities between 1.3 and 1.0 (curve *AC*) or between 1.3 and 0.7 (curve

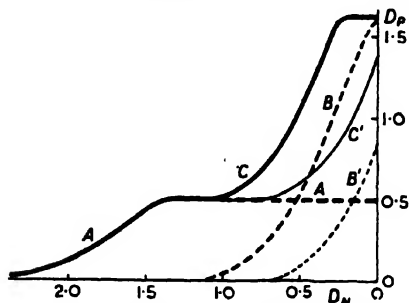


FIG. 41.5. CHARACTERISTIC CURVE OF PRINT WITH COMPRESSED HALF-TONES

AC') are represented by the same density 0.5 on the print. The print represented by curve *AC'* has no blacks, whereas that represented by curve *AC* has maximum blacks for all negative values between 0 and 0.2. The perfect print would have been obtained by using an intermediate exposure time when copying from the original negative.

The Person process, in common with other procedures which will be described later, requires a very precise control of the various operations involved and it cannot be too strongly recommended that a step-wedge be attached to the original negative, which will be reproduced on the duplicate negative and on the print, outside the useful margin. It will also be found useful if register marks consisting of two fine lines at right angles, are made in the margin of the negative at the ends of a diagonal. These should be reproduced on the intermediate positive and duplicate negative and will be found very useful in registering the successive exposures when making prints.

Among the variants of this process which have been proposed, the inverse method employs a very soft original negative, which thus has a low graininess, for obtaining the shadows. From this is made a copy negative of high contrast for obtaining the high-lights (W. Anderau, 1936).

Sensitized coatings which give a stepped characteristic curve, the tangent to the curve

at the point of inflexion being only slightly inclined from the horizontal, have been proposed. These may be prepared by mixing or superimposing a slow high-contrast emulsion and a more rapid emulsion which rapidly reaches its maximum density and does not show inversion except by considerable over-exposure. Such materials have been suggested by G. Cordonnier (1936) and later prepared experimentally by W. Schwerzer (1943) and used successfully in the preparation of duplicate negatives. These plates need a very precise determination of exposure time and are therefore not very suitable for direct photography.

732. Compression of Middle Tones by "Harmonization" of the Print. Results very comparable to those which may be obtained by the methods described above, may be obtained more simply, but perhaps less reproducibly on several prints from the same negative, by a method due to H. Zickendraht (1938-9). The print is placed in a bleaching bath (§ 737) until the silver is converted into bromide or chloride to a depth about two-thirds the thickness of the emulsion coating. The silver salt is then surface developed or sulphided and the remaining middle layer of silver halide dissolved out. The author has been able to obtain some remarkable results by this method; control of the treatments is much easier on plates or films, since the penetration of the various baths may be more easily followed by observing through the base a step-wedge printed on one of the margins, especially if the extreme densities occurring in the image are marked and the interval between them divided into three equal parts on the wedge.

The rate of penetration of the baths may be slowed up by the addition of alcohols, high concentrations of neutral salt (sodium sulphate) or thickeners. It is preferable to use for the treatments baths whose rates of reaction are greater than their rate of penetration into gelatine. The best results have been obtained by bleaching in a solution containing 1 per cent of ferricyanide and 1 per cent potassium bromide and, after washing, blackening by sulphiding in a solution containing 2 per cent of sodium monosulphide. The image obtained has a double tone, the high-lights having a warmer tint than the shadows. This effect is sometimes agreeable but if it is not, then after removal of the remaining silver halide and washing, the silver which was unaffected by the first treatment should be bleached and sulphided in the same manner.

733. "Stylization" of Images by Substitution of Continuous Tone by a Limited Number of Flat Tints. A method has been described by W. Romer (1932) under the name "isohelie" in which the continuous grey tones are replaced by a limited number of uniform densities, for example white, two greys, and a black, limited to curves of equal density on the negative corresponding to 80 per cent, 50 per cent, and 20 per cent of the maximum brightness of the subject. This result is obtained indirectly, by making intermediate copies on high-contrast sensitive materials, first positive transparencies with exposure times conveniently spaced and developed to maximum density, then negatives on thin film which may be placed in register to form the final negative. The individual components of the final negative should show only two densities and the maximum density should be the same for each and should not be greater than 0.3 to 0.4, in order that prints may be made from the composite negative.

If the intermediate positives show half-tones they should be weakened or suppressed by superficial reduction followed by a strong intensification.

734. "Stylization" of Images by Means of a Black Border. To weaken the photographic character of portraits or personal studies, Man Ray (1933) has described a method which he incorrectly referred to as "solarization" but which makes use of the Sabattier effect (§ 209). A paper negative of good contrast prepared from a positive print or by enlargement from a transparency is developed as usual, development being stopped before fog appears in the unexposed parts. Surplus developer is then removed by swabbing, the paper exposed to white light and the reversed image allowed to develop in the small amount of developer remaining in the emulsion layer. The paper negative is then fixed and finished in the normal manner. Prints made from such a negative are not very different from the original but the principal contours are surrounded by a strong dark grey line. Fig. 41.6 is a reproduction of a photograph obtained in this way.

TONING AND TINTING OF TRANSPARENCIES AND PRINTS

735. Introduction. Whatever may be the method of toning selected, success will be obtained only if all the previous operations have been carried out with the utmost care. It is essential that plates, films, and paper prints

should have been fixed in two baths and washed very thoroughly.

Methods of toning vary as regards the degree of success with which they may be used with images in which the silver exists in grains very different in size: certain methods of sulphide toning are only applicable to chloride papers, whilst others are more suitable for use with



FIG. 41.6. 'STYLIZED PRINT

bromide papers where the grain size is much less fine. Various conditions in working, such as the composition of the developer, more or less prolonged development, etc., can exercise a marked effect on the final colour of the toned image.

The fact that the silver image is converted into one consisting of a different substance involves necessarily a variation in the value of the different densities. In most cases toning is an intensification process; in a few rare instances it occasions a slight reduction.

While a very slight grey deposit is generally passed unnoticed, a coloured tone of corresponding depth is almost always glaring. It follows that images to be toned should have perfectly clean whites. As a precautionary measure, prints intended for toning may be cleared in the hypo and ferricyanide reducer, used very dilute, and preferably in alkaline solution.

The reagents used in certain toning processes are retained very tenaciously by the paper

itself or by the substratum. Special precautions are therefore necessary for toning prints on paper which do not apply when toning images on an inert support.

Toning processes are almost infinite in number, though many of them have lost their interest through the introduction of new methods, which consist in converting the silver image into a mordant capable of fixing very various dyes. This method allows the choice at will of any desired colour under the most economical conditions, without any variation in working other than the choice of a dye, or a mixture of dyes, of a suitable shade.

All toning baths attack all metals as they attack silver. Metal containers or accessories, even enamelled or varnished, cannot be used for these operations.

Before entering upon a description of the principal methods of toning, it is desirable to emphasize, as strongly as possible, the discretion which should be exercised in the production of prints in bright colours (§ 597).

736. Sulphide Toning: General Considerations. Silver sulphide (Ag_2S) which, in the mass is black, assumes various colours, from yellowish-brown to purplish-brown, when finely divided. Silver sulphide is extremely stable and is unaffected by atmospheric conditions. When sulphiding the silver image obtained by development, it is desirable to obtain a sepia-brown or warm brown colour, more transparent in the shadows than the original black silver image, and avoiding the yellow-brown "mustard" tone at one extreme and the purple at the other. Yellowish tones are produced by conditions which tend to give very fine grain, for example chloride or chloro-bromide papers which are over-exposed and under-developed, or have been reduced, whereas purple-brown tones are produced by conditions giving relatively large grains, for example bromide papers or forced development of under-exposed prints.

Prints developed in metol-hydroquinone are often more yellow after toning than those developed in amidol.

The conversion of the silver into silver sulphide can be effected by direct combination of the silver and sulphur, the latter being obtained from a colloidal solution in which the particles are extraordinarily fine, as, for example, in a warm solution containing sodium thiosulphate (hypo) and alum (L. Baekeland, 1888), or an acid (Lumière and Seyewetz, 1912). A weak solution of polysulphide may also be used for

the direct sulphuration of the silver, as purchased (J. Desalme, 1913), or prepared at the time of use by the addition of an oxidizing agent to a solution of monosulphide (Kropf, 1910).

Sulphiding can also be effected indirectly, the silver being first converted into a salt such as chloride or bromide—bleaching of the image—which, by means of a second operation, is converted into silver sulphide by means of a solution of sulphide (Blake Smith, 1902), of a sulphiding mixture, or even, sometimes, by means of gaseous hydrogen sulphide.

Except when using odourless sulphiding mixtures (§ 738), sulphiding must always be carried out at a sufficient distance from all stocks of sensitive photographic materials, and from rooms in which they are handled in their original condition, in order to avoid the intense fog which is always caused by the action of traces of hydrogen sulphide on photographic emulsions.

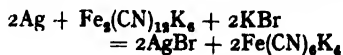
The indirect process of sulphiding¹ is the method which, almost always, is the best for lantern plates and prints on bromide papers. Direct sulphiding is most suitable for the fine-grain images on chloride or chloro-bromide papers, although there is no hard and fast rule.

Nevertheless, compensation is thus obtained for the tendency of indirect toning to give more yellow tones and for the tendency of rapid emulsions to yield purple tones, and inversely.

Direct sulphiding often produces no apparent effect on bromide papers but the fact that a reaction has taken place may be shown by treating with a reducing agent, which will dissolve the unattached silver and leave a warm-toned image.

Transparencies for sulphide toning ought to be kept rather thin, no appreciable effect being apparent in a very dense transparency seen by transmitted light.

737. Bleaching for Sulphide Toning. Most frequently the silver forming the image is converted into silver bromide by immersion in a solution containing ferricyanide and potassium bromide. The ferrocyanide, produced in the absence of a soluble bromide, is only formed very slowly. The equation of the reaction



renders it easy to calculate the proportions of ferricyanide and bromide corresponding to

¹ Toning with two baths often gives less warm tones on mat papers, than on glossy ones of the same brand treated in identical conditions.

their simultaneous exhaustion in the bath—659 and 238, approximately 30 and 11. It is necessary to increase very slightly the amount of bromide calculated by this formula so as to ensure a constant excess of this salt. A used bath may be regenerated by the addition of bromide and a bichromate which will re-oxidize the ferrocyanide to the state of ferricyanide.

It should be noted that the ferricyanide of the bleaching bath will form, in combination with the hypo from an imperfectly washed print, the Farmer reducer, and generate a more or less uniform reducing action on the print. This bath should be made alkaline by the addition of a little ammonia or, better still, sodium carbonate, in order to prevent the formation of blue fog or spots due to slow decomposition of ferricyanide acid absorbed by the gelatine. This will also considerably accelerate the washing of the bleached prints and thus avoid reduction of the images with formation of yellowish tones which result when badly washed prints (containing more ferricyanide which will tend to convert monosulphide into polysulphide which is slower and more superficial in its action) are treated in a sulphide bath which is partially oxidized to thiosulphate (hypo) (E. E. Jelley, 1932). The following bath, which is perfectly stable and may be used till exhausted, is given as an example—

Potassium ferricyanide	30 g
Potassium bromide	12 g
Sodium carbonate, anhydrous	15 g
Water to make	1000 ml

Sepia tones are obtained most easily from iodized images, a suitable iodizing bath containing 30 g of ferricyanide, 10 g potassium iodide, and 20 ml of ammonia, per litre of solution.

The silver may also be converted into chloride by using a solution of permanganate and a chloride, suitably acidified, the final colour of the image then tending to become purple.

This solution may be used for the conversion of a sulphided image into chloride, if the colour is not pleasing, or for treating an old print partially sulphurized by atmospheric impurities. If the whites should be slightly tinted by the action of this bath, the staining may be entirely removed, after rinsing the print, in a very weak solution of sodium bisulphite.

The use of metallic salts, such as cupric chloride or mercuric chloride, in bleaching solutions for toning, is to be studiously avoided. They form a salt, cuprous or mercurous, which intensifies

the image and destroys the transparency of the deposit.

Prints bleached directly they are taken from the washing water after fixing tend more towards purplish tones than dried prints. The tone of prints which have been dried is not modified by a preliminary soaking before bleaching. It has been pointed out many times that immersing a print in the sulphide solution, followed at once by bleaching without intermediate rinsing, gives tones intermediate between those produced by direct sulphiding and indirect sulphiding. The time of immersion in the bleaching bath, after the complete conversion of the initial black silver into the white halide salt, has no effect on the final tone of the image. Incomplete bleaching of a print in a very dilute solution allows effects of double toning to be obtained, the light tones being formed entirely of sulphide of silver and the shadows of a mixture of brown silver sulphide and black silver. Other effects can also be obtained, after fully bleaching and washing, by partial re-development in a very dilute developer for warm tones, in full white light, or, by exposing the wet print to a strong light until the image has become visible by direct darkening. After sulphiding, the print will be uniform in colour, formed partly by the silver image and partly by silver sulphide. The temperature of the bath also has no effect on the tone produced. If the bromiding bath given above is used, variations in strength due to its gradual exhaustion have no influence on the final colour. The final colour, after toning, however, tends towards yellowness if the washing after bleaching is prolonged. A very short washing after bleaching is sufficient, none of the constituents of the bleaching solution having any influence on the sulphiding. The action of light on the print between bleaching and sulphiding does not in any way influence the final result provided no visible image is produced.

Bleached prints should be washed for about 10 minutes before being placed in the sulphide solution.

In the course of a very thorough study of the influence of different working conditions on the final colour of the prints toned by this process, E. R. Bullock (1921) has ascertained that when a print, bleached in either a neutral or acid bath, is placed, before sulphiding, in a solution of sodium carbonate, the final colour of the image is distinctly modified. An immersion of about 10 minutes in a solution of about 0.5 per cent strength of anhydrous sodium carbonate

gives tones slightly more purple, the effect being more marked with chloride prints than with bromide. A more concentrated solution is less effective. A few preliminary tests will readily show the best strength of solution for a particular paper and given working conditions.

738. Sulphiding the Bleached Image. Sulphiding is generally done by means of a solution of sodium monosulphide.

Sodium monosulphide, or neutral sodium sulphide, $\text{Na}_2\text{S}\cdot 9\text{H}_2\text{O}$, occurs in the form of deliquescent crystals, which should be free from discoloration if chemically pure, but which are generally amber-coloured or even a dull green or black on account of the presence of iron sulphide in a state of very fine division. Sodium monosulphide emits an odour similar to rotten eggs, characteristic of hydrogen sulphide gas. On exposure to the air it is converted slowly into caustic soda, thiosulphate, and polysulphides—sulphides containing a larger proportion of sulphur. It must be kept in glass jars, hermetically sealed. It may be kept with advantage under a film of benzene or mineral spirit, which prevents it from absorbing moisture from the air and becoming decomposed. Sodium monosulphide is very soluble in water, especially hot water. Solutions of a strength of at least 20 per cent keep quite well: very weak solutions change rapidly, forming principally thiosulphate which would dissolve the whole or part of the image instead of sulphiding it. Solutions of sodium monosulphide have, although less strongly marked, the caustic properties of solutions of sodium carbonate. Concentrated solutions cause the skin to swell, and disintegrate gelatine. To obtain a clear and almost colourless solution from the ordinary samples of monosulphide, the salt should be dissolved in a small quantity of water, and the solution then brought to boiling point and kept there for about 10 minutes. On cooling, the iron sulphide coagulated by boiling settles to the bottom of the bottle, and the supernatant clear liquid can then be decanted. In this manner a solution of a strength of 50 per cent can be prepared, which can be diluted when required for use. Sodium sulphide frequently blackens enamelled articles (lead enamels), dishes, sinks, saucepans, baths, etc.; concentrated solutions cannot be filtered through paper, owing to their action on the filter paper. The liberation of hydrogen sulphide gas due to the hydrolysis of these solutions can be diminished by using glycerine or glycol for their dilution.

The solution is usually used at a strength of 0.5 or 1 per cent (prepared at the time of use by diluting a concentrated stock solution), which is thrown away immediately after using. The image is completely converted into sulphide in about one minute.

The use of more concentrated solutions frequently imparts a yellowish tint to the gelatine and paper, which may be removed, after rinsing, by immersion in an acid bath (1 per cent hydrochloric acid).

The use of very weak solutions, or solutions containing an appreciable proportion of thiosulphate and polysulphides formed by oxidation, tends towards the production of yellower tones than those by the normal treatment. The use of a polysulphide, e.g. *liver of sulphur*, in place of the monosulphide likewise produces tones more yellow than the normal colour. The silver sulphide of images sulphided by a polysulphide is not pure sulphide of silver. The disagreeable yellow tones thus obtained are much improved by immersion in a dilute solution of silver nitrate which would have no action on normal silver sulphide. After this treatment of all images sulphided to a yellow tone, the prints must be rinsed, placed in a fresh fixing bath, and washed again (K. C. D. Hickman and W. Weyerts, 1933).

The essential condition for obtaining pure whites is that the gelatine should be perfectly free from every trace of a residual silver salt arising from imperfect fixing. To ensure this condition, the fixing must have been done in a 20 per cent solution of hypo containing not more than 2 g per litre of silver bromide (Lumière and Seyewetz, 1923).

It has been proposed to replace the sodium monosulphide by compound sulphides which would deposit another sulphide on the brown image. For example, sodium sulphoantimonate (Schlippe's salt) deposits on the silver sulphide formed a little orange-red antimony sulphide (Carey-Lea, 1865). The resulting image is of red-chalk colour, but with an entire loss of transparency and frequently with the whites more or less tinted.

The surest means for avoiding any smell (and the fogging due to hydrogen sulphide) is to carry out the sulphiding of the image with a solution containing both thiourea and an alkali. The latter transforms into sulphide of silver the insoluble compound which has first formed between the silver halide and the thiourea. (I.-G. Farbenindustrie, 1931). The use of

seleno-urea will give similar results under the conditions required for selenium toning.

The solution may be made alkaline by the addition of caustic soda or sodium carbonate. In the first case an excess of thiourea tends to give a yellowish tone and an excess of caustic soda a violet tone. When carbonate is used, the reverse occurs and excess of alkali tends to give yellowish tones (A. Seyewetz, 1934). A solution of 1 per cent sodium carbonate, with an addition of 5 ml per litre of 2 per cent thiourea, may be used. This mixture, which is very stable, may be used until it is exhausted. Sulphiding is complete in about 4 minutes. An ammoniacal solution of thiourea may be used for direct sulphiding of reduced silver, but the reaction is very slow unless the silver is in a very finely divided state.

739. Direct Sulphiding. Single-bath sulphide toning is sometimes carried out using a 10 per cent solution (approx.) of liver of sulphur. Liver of sulphur or Bareges salt is a yellowish-brown substance, often covered with a greenish-grey crust formed by oxidation. Besides the polysulphides of sodium (trisulphide and pentasulphide) it contains sodium carbonate, sodium thiosulphate, and sodium sulphate. It swells in moist air with evolution of hydrogen sulphide and will split a glass or stone-ware jar. For this reason it is often supplied and stored in a metal container. It is very soluble in water and the solution which is reddish-brown in colour is stable if the concentration is at least 20 per cent. Decomposition takes place rapidly at low concentration.

The toning process using liver of sulphur solution is very slow and it is impossible to stop the toning at an intermediate tint because the sulphiding continues to finality during washing and drying. The presence of thiosulphate in the commercial product prevents discoloration of the whites of badly fixed prints.

The bad keeping properties of liver of sulphur have led occasional workers to prepare their own concentrated solution of polysulphide, since this will keep quite well in well-stoppered flasks. Fifty grammes of crystalline sodium monosulphide should be dissolved in about 50 ml of water in a glass or porcelain container and brought to the boil. Ten grammes of sulphur should then be added a little at a time with stirring. "Stick" sulphur broken into small fragments should be used since "flowers" of sulphur does not wet at all easily and will therefore not dissolve completely. The pre-

paration should be carried out in a well-ventilated room, away from stores of photographic materials. When the sulphur is dissolved, allow to cool and add water to bring the orange-yellow solution, which is mostly bisulphide and trisulphide, to a volume of about 250 ml.

For use, this stock solution should be diluted with 10 to 20 times its volume of water. The liquid obtained is usually milky and behaves like a colloidal solution of sulphur.

When immersed in this solution, prints tone slowly in the cold but more rapidly in a warm bath. They should be transferred to the washing apparatus after about 20 minutes.

740. Cold Sulphiding with Acidified Hypo. A well-fixed print, after rapid rinsing, may be toned by immersing in a plain solution of hypo—about 20 per cent—and transferring from that directly to a very weak solution of hydrochloric acid—about 1 per cent. The print must remain in this bath for at least half an hour; if not, there is a risk that the final colour will not be the same throughout. The final colour is only obtained after washing for about an hour and a half (Lumière and Seyewetz, 1913). If washing is interrupted before toning is complete, toning will continue during drying and is very rapid if drying is done under heat.

741. Direct Sulphiding with Hypo-alum. Papers giving a warm black tone by development may be sepia-toned in a warm solution of sodium thiosulphate (hypo) and potassium aluminium alum. When a solution containing hyposulphite and common alum is boiled for a few moments (§ 493), the precipitate which is formed first consists chiefly of alumina. If this mixture is allowed to cool, the reaction continues for a long time. In addition to the sulphur which is deposited, the liquid must be considered as being a solution of colloidal sulphur. A print immersed in this solution becomes sulphided very slowly if the bath is cold, but rapidly at a temperature of 120° to 140°F. New baths always attack, more or less, the details in the light tones of the prints which are toned in them; old baths are free from this defect and yield very fine tones. Consequently, used solutions should never be thrown away but replenished from time to time with a quantity of new solution. New baths can be "ripened" by dissolving a little silver nitrate in them, or by adding trimmings of sensitive paper. The fact that the toning bath always contains silver salts led Baekeland to advise subjecting prints toned in it to re-fixation in a new bath. It is to be

regretted that this precaution is usually neglected, with the result that a slow yellowing of the whites of the prints may ensue.

The toning bath may be prepared as follows: 200 g of hypo should be dissolved in 1 litre of hot water. To this should be added 450 g of common alum, powdered. The mixture should be shaken, boiled for 2 or 3 minutes,¹ allowed to cool to about 150°F, and then addition made of about 0.5 g of silver nitrate dissolved in about 15 ml of water, with sufficient ammonia to re-dissolve the precipitate which the first drops of ammonia produce. The bath must be thoroughly stirred and, finally, 1 g of potassium iodide dissolved in a little water should be added.² This bath should be used at a temperature between 120° and 140°F.

It is, therefore, necessary that the gelatine prints shall have been hardened before toning in a fixing bath containing alum, or, at any rate, by immersion in a cold saturated solution of alum.

When the prints are taken from the toning bath they must not be washed until they have become quite cold. They are left for a few minutes in any empty dish to cool. Neglect of this point is a frequent cause of blisters. During cooling the prints should be sponged with a tuft of cotton wool moistened with tepid water, so as to remove the deposit of sulphur formed on their surfaces. This is prominent after drying, but it is then very difficult to remove.

742. Gold Toning. The methods of gold toning with sulphocyanide, or with thiourea, previously described (§§ 663 and 665) for print-out papers, are equally applicable to development papers. They yield bluish tones, chiefly of value for transparencies and very useful for improving warm-toned transparencies of unpleasant colour. Prints on paper do not give pleasing bluish tones by this method unless the print has been developed to a warm colour, in a dilute solution, with considerable over-exposure, particularly with chloro-bromide paper (A. Steigmann, 1926).

This method is particularly interesting for black-tone transparencies and warm black prints. With black-tone prints of relatively large grain size, there is generally no visible effect.

¹ If the toning bath is being made up in quantity larger than the capacity of the vessel for heating it to boiling point, the alum may be dissolved in about a quarter of the total volume of water, and the boiling solution of alum added to the solution of hypo.

² It has also been proposed to add to this mixture a small quantity of chloride of gold.

Warm-tone transparencies which have an unpleasant tone may sometimes be corrected by this method, the resulting tint depending on the initial tone and the duration of toning.

The same toning baths, used with prints which have already been toned by the sulphide processes, produce red tones ranging from red-chalk to carmine (A. H. Dunning, 1907). The image then consists of silver sulphide and gold sulphide. There is no reduction in the quantity of silver sulphide present in the image before the gold toning. Red-chalk, the tone most desired in this toning process, is obtained most easily, as a rule, with prints which have been over-exposed and developed in a dilute solution, and are yellowish when sulphide-toned (J. Hertzberg, 1923). The process is especially suitable for portrait studies against a white background.

743. Toning with Selenium. The seleno-sulphide toning bath previously given for print-out papers (§ 669) can be used equally for developed prints on papers with emulsions of very fine grain—gaslight and chloro-bromide. With them it gives a beautiful sepia-brown tone. This method of toning is applicable to prints already toned by the sulphide process. It then yields red tones (E. R. Bullock, 1917). Although this bath deposits selenium on the image produced on bromide paper, no change in the original black colour of the print results.

The fact that selenium is, however, deposited on the silver will be noticed if the latter is removed by Farmer's reducer, the residual image being formed exclusively of selenium ranging from red to orange according to the state of dispersion of the silver in the initial image (P. Rehlander, 1932).

744. On fine-grain images a sepia-brown tone may be obtained by treatment in a solution of sodium seleno-sulphide (Rheinische Emulsions-fabrik, 1910), prepared, for example, by dissolving (under the same conditions already described in § 739 for the preparation of polysulphide) 50 g of monosulphide in 50 ml of water and introducing 5 g of powdered selenium into the boiling solution. This solution should be diluted to about 250 ml and the reddish-brown stock solution thus obtained further diluted at the time of use with 10 times its volume of water, or preferably a 1 per cent solution of sodium monosulphide. The latter will prevent the rather rapid oxidation by air with formation of a red deposit of selenium which may cause a yellowish fog on the print.

The same stock solution of seleno-sulphide, diluted with water or monosulphide as above, may also be used to tone prints which have been previously bleached (§ 737), whether they were on bromide or chloride paper. The tones obtained are usually a purplish brown and any coloured fog formed may be removed by a short immersion in a dilute bisulphite solution. The image which is obtained in this way consists of silver selenide in association with a varying proportion of silver sulphide. A used bath will tone a considerable number of prints but cannot be stored for future use owing to its rapid decomposition on standing. If left exposed to air, selenium will be deposited and can be recovered from the bath in this way.

Colloidal solutions of selenium are of no use for toning. Toning may also be carried out similarly using tellurium in place of selenium. Tellurium has similar properties to selenium but is more expensive.

745. General Considerations on Toning by the Formation of Coloured Ferrocyanides. The formation of coloured ferrocyanides was suggested as a method of intensification (H. Selle, 1866), and, later, as a toning process. It has been the subject of numerous investigations (R. Namias, 1894; L. P. Clerc, 1899, etc.).

The ferrocyanides of most of the heavy metals are insoluble compounds of very bright colour, and thus this method affords very varied effects.

The coloured ferrocyanide, of which it is desired to form the image, can in every case be obtained by first converting the silver of the original image into silver ferrocyanide by immersion in a solution of potassium ferricyanide according to the reaction previously described in reduction (§ 556). This intermediate compound is then treated with a salt of the metal of which the ferrocyanide is desired (*two-solution toning*).

When the ferricyanide of the metal of which the ferrocyanide is required is soluble in water, or in a solution of which the constituents have not, in themselves, any action on the silver of the original image nor on the ferrocyanide desired, the operation can be carried out in a single bath. As the silver is converted into ferrocyanide, the used ferricyanide passes to the state of ferrocyanide of the same metal, which is deposited on the image at the point where it is formed. The ferricyanides necessary for these reactions are not commercial articles; it is therefore necessary to use equivalent

mixtures of potassium ferricyanide and a salt of the desired metal.

The following table gives the colours of a number of insoluble ferrocyanides, and also states whether the corresponding ferricyanide is soluble in water and, if not, the substance which is best used for making a solution.

Ferrocyanide	Colour	Solvent to be used for dissolving the ferricyanide
Cadmium ¹	White	Neutral solution of potassium citrate
Cobalt ²	Greenish-blue to purplish-red	Neutral solution of potassium citrate
Copper (cupric salts)	Purplish-red	Neutral solution of potassium citrate
Iron (ferric salts)	Prussian blue	Water
Lead ³	White	Water
Molybdenum	Dead-leaf brown	Water
Nickel ⁴	Reddish-brown	Neutral solution of potassium citrate
Titanium ⁵ (titanic salts)	Yellow	Water
Uranium ⁶ (uranyl salts)	Reddish-brown to fiery-red	Water
Vanadium ⁷	Light orange-yellow	Water

After-treatment by an oxidizing agent (chromate, permanganate, and hydrogen peroxide in acid solutions) may transform the ferrocyanide into ferricyanide and the same change

¹ Treatment with a solution of monosulphide gives, according to whether the silver ferrocyanide has been eliminated or not, a yellow image of cadmium sulphide (H. W. Rimback, 1935) or a sepia brown which is due to the mixture of yellow cadmium sulphide and silver sulphide. It should be noted that cadmium salts are toxic.

² The image is greenish-blue when produced by the two-bath method (action of cobalt chloride on silver ferrocyanide) or violet red (prune coloured) when produced by the single-bath method, the cobalt being used as a sulphate in the presence of citrate (J. Dubreton, 1919).

³ Lead ferrocyanide may be converted into yellow lead chromate (chrome yellow) by immersion in an alkaline chromate or bichromate solution. For two-bath toning it is frequently recommended that lead ferrocyanide be formed first in order to obtain a greater amount of reactive ferrocyanide which will give a denser final image (Eder and Toth, 1876).

⁴ Nickel ferrocyanide may be converted into an intensely red compound. After thorough washing, the image should be treated with an alcoholic solution containing 1 per cent dimethylglyoxime made alkaline with a small amount of caustic soda. (F. Lejeune, 1930). The red compound is destroyed by acids.

⁵ The technique of toning with vanadium and titanium has been described by E. J. Wall (1921 and 1927).

⁶ As the colours given respectively by iron toning and uranium toning are complementary, these methods have been applied to the production of two-colour prints in the motion-picture industry.

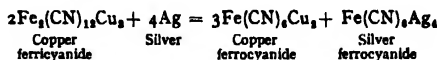
may be produced by a prolonged treatment in a single-bath toning solution, the role of oxidizer being played by the excess of ferricyanide in an acid condition. It is in this way that the reddish-violet cobalt ferrocyanide may be converted into the insoluble reddish-brown ferricyanide (Strauss, 1923) and the reddish-brown nickel ferrocyanide into the yellow ferricyanide (P. Bonneau, 1941).

It will be understood that, after toning in a single bath, the image contains, in addition to the coloured ferrocyanide which it was intended to form, also silver ferrocyanide. If this were left in the image it would give rise to a superficial metallic lustre, due to sulphuration by atmospheric impurities. (This may be avoided by varnishing the image.) Consequently, it is usual to dissolve out this salt when toning is finished. This increases the transparency of the image considerably, and is, consequently, specially useful when images are to be viewed by transmitted light. But the silver ferrocyanide can also be utilized to form in the image an additional quantity of a coloured ferrocyanide, identical with that already formed, or different, according to the method of toning in two baths, and thus intensifying the image or modifying its colour. Further, in order to obtain blended colours, the silver ferrocyanide may be reduced to the metallic state by development in daylight, or it may be converted into silver sulphide. As the metallic ferrocyanides are mostly decomposed in alkaline baths, all these conversions should be effected in acid solutions.

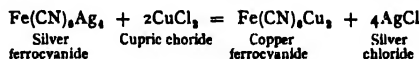
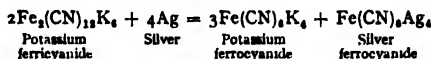
The conversion of silver ferrocyanide into another insoluble ferrocyanide is most frequently done in a solution of the chloride of the metal of which it is desired to obtain the ferrocyanide, or, failing the chloride, in a solution of another salt to which hydrochloric acid has been added. The conversion is frequently more rapid or more complete in the presence of a bromide. When toning in a single bath is carried out with a solution containing a chloride or a bromide, and this addition does not produce a salt capable of chloriding or bromiding direct the metallic silver without the intervention of the ferricyanide (which is the case, for example, in blue toning with iron, or red toning with copper), the conversion of the ferrocyanide of silver into a coloured ferrocyanide is effected as it forms, the coloured image being then appreciably denser. After the toning is completed the image contains silver chloride liable, in time, either to become converted into metallic silver, or to be

darkened by exposure to light, and in either case increasing the opacity of the image considerably. It is therefore necessary to remove this salt, unless it is desired to obtain particular effects from its darkening by exposure, from its reduction to the metallic state, or by sulphiding.

When forming the same coloured ferrocyanide the quantity of this ferrocyanide formed from the same original quantity of silver is appreciably greater by toning in a single solution than when two successive solutions are employed, a denser coloured image being obtained. Consider, for example, the case of toning with copper. When toning in a single bath, the reaction is—



while the reactions occurring by toning in two successive solutions are—



In principle, the same quantity of silver would produce by the first method three times more copper ferrocyanide than by the second; or four times if one applies a bath of cupric chloride to the image already toned in a single bath. All the precipitated ferrocyanides, even in the presence of the other constituent, contain an excess of potassium ferrocyanide absorbed or combined in the state of a compound such as $\text{Fe}(\text{CN})_6\text{Ag}_3\text{K}$, $[\text{Fe}(\text{CN})_6]_2\text{Cu}_2\text{K}_2$, etc.

746. All reducing agents, and particularly thiosulphate, which are left in the gelatine or paper due to bad fixing or incomplete washing, cause a reduction of ferricyanide and a deposit of coloured ferrocyanide in the form of veil or stains. It is therefore recommended that images which are to be toned, and particularly paper prints, should be treated with an effective hypo eliminator (§ 513).

The gelatine (and also the coating of the paper) during the course of the operations, particularly when these are carried out in very acid solutions, may retain yellow hydroferricyanic acid, which cannot be removed by washing in plain water, and produces a uniform discoloration, especially noticeable in prints on paper (Lüppo-Cramer, 1912). This can be removed, after the operations

are completed, by immersion in a moderately concentrated solution of sodium sulphate from 2 to 10 per cent, preferably containing, in addition, a small quantity of sodium or potassium citrate, about $\frac{1}{2}$ per cent. This clearing bath may be used several times in succession.

The decomposition products of ferricyanide which form a coating of crystals on the surface may be eliminated by rinsing. To make certain that the bath contains no ferrocyanide, a small quantity of an oxidizing agent such as potassium bichromate or ammonium persulphate should be added frequently; in this way a clear mixture is obtained.

In the case of toning in a single bath, the same reaction which is produced on the silver of the image can also be produced on any other metal brought into contact with the solution. For that reason the use of metal dishes must be avoided, as well as metal forceps, frames, etc., or any appliances with metal parts, which would rapidly exhaust the solution.

When toning with a single bath, the gelatine not only retains a little ferricyanide, but also a little of the other essential constituent of the solution—iron salt, uranium salt, etc. The solution used for toning induces a strong tanning action on the gelatine. This tanning effect, and the concurrent combination of the salts with the gelatine, are very much less in baths which contain a relatively large proportion of citrate, but the presence of citrate tends in certain cases to render the toning solution inert, especially in uranium toning, unless a bath containing a large proportion of hydrochloric acid is employed. The combination of the salts with the gelatine is restricted by adding to the bath a salt which has a greater affinity for gelatine, e.g. alum (E. Sedlaczek, 1920).

There is sometimes a risk that the coloured ferrocyanide may be formed on the exterior of the film on account of the diffusion of the soluble intermediate ferrocyanide (potassium ferrocyanide). This occurs most where the image is densest, and where, consequently, the ferrocyanide can form a more concentrated solution. This result, which might cause a local inversion of the image, may be avoided by regulating the proportion of the constituents of the toning bath in such a manner that the metallic salt, of which it is desired to form the ferrocyanide, is always in considerable excess relative to the ferricyanide. This precaution is the more necessary as, in addition to the

insoluble ferrocyanide, certain metals—uranium, molybdenum—yield a relatively soluble ferrocyanide when formed from an excess of potassium ferrocyanide. In addition, in direct toning, agitation of the bath should be avoided as much as possible.

In addition to the full colour resulting from toning carried as far as it will go, (bright colours are required for several special purposes and especially for the making of positives in three-colour processes) it is practicable, by incomplete toning, to obtain tones intermediate between the colour of the ferrocyanide and the black of the initial image. These intermediate tones are frequently far more pleasing than the final colours, which may be too bright. It is easier to obtain these intermediate colours when toning in a single solution, as the image retains almost the same tone that it possesses when the toning action is stopped.

747. Reddish-brown Toning with Uranium, in Single Solution. Toning with uranium intensifies the image in proportion as it is carried to finality. A print of normal contrast may be toned to a warm black by a short immersion in the toning bath, but toning to red-brown or bright red requires a print of considerably less than average contrast.

It is preferable to prepare the toning bath, at the time of use, from 10 per cent stock solutions. Old baths can, however, be used, but they must be filtered if they have become cloudy, and a little more acid added if toning is slow.

Of the two formulae for toning baths given, No. 1 tends to produce redder tones than No. 2. Uranium tones are stated by A. M. Gundelfinger (1934) to be complementary to those obtained using iron.

	No. 1	No. 2
Uranium nitrate, 10% solution	25 ml	25 ml
Neutral potassium oxalate, 10% solution	25 ml	—
Neutral potassium citrate, 10% solution ¹	—	25 ml
Potass. ferricyanide, 10% solution	10 ml	10 ml
Ammonium alum, 10% solution	50 ml	—
Hydrochloric acid, 10% solution	5 ml	50 ml
Water to make	1000 ml	1000 ml

¹ Neutral potassium citrate $K_2C_6H_5O_7 \cdot 2H_2O$, is in small crystals, free from colour, and very soluble in water. It can be replaced by practically the same weight of neutral sodium citrate. In all solutions of citrates a mouldy growth appears in course of time. This may be prevented by the addition of an antiseptic to the solution, e.g. a small quantity of phenol, or by keeping a fragment of camphor floating on the solution. With many insoluble salts, citrates form complex soluble salts.

The solutions should be pale yellow and perfectly clear.

Toning is very slow at first, becoming more rapid as the operation progresses. According to the tone desired, toning may require from 2 to 10 minutes. Half a litre of bath will tone about 2½ sq ft.

When toning ciné film introduced into the bath in the dry state, the bath is maintained at constant activity by the addition of 2 litres of a solution which is five times as concentrated as the initial bath for every 600 metres of film processed.

When the image is toned to the desired extent it must be washed. But uranium ferrocyanide is exceedingly susceptible to the action of alkalis, even the weakest, and it would be decomposed (and the colour discharged from the image) by the calcium bicarbonate usually present in ordinary tap water. This reducing action may be avoided by adding a very little acid to the wash water, e.g. 1 part of hydrochloric or acetic acid to 1,000 parts of water. In practice about 1 ml of concentrated acid may be added per litre, or 5 g of boric acid. A very brief rinsing in plain water completes the washing.

The uniform yellow tint of the base which generally remains after this method of toning is not displeasing in the case of transparencies, but with paper prints the effect is distinctly disagreeable. It can be removed by immersing the print in the clearing bath given in § 746 until the whites are clear, after which the prints are rapidly rinsed.

If necessary, any residual salts of silver should be dissolved out in an acid fixing bath, either freshly prepared or kept exclusively for this process. The following fixing solution may be employed—

Hypo	50 g
Sodium acetate	10 g
Acetic acid, 10% solution	10 ml
Water to make	1000 ml

The prints, which should be rinsed before fixation in an acid bath and then in ordinary water, should finally be well washed in acidified water. Removal of the silver salt is useless if the toning has been stopped at a warm black or sepia tone.

748. Blue Toning with Iron, in Single Solution. Toning with iron intensifies the image in proportion to the degree to which the toning action is taken, particularly if the residual silver salts are not eliminated.

The following toning bath may be used (Kodak Ltd., 1948)—

Ammonium persulphate	0.5 g
Iron ammonium sulphate (Ferric alum)	1.4 g
Oxalic acid	3.0 g
Potassium ferricyanide	1.0 g
Ammonium alum	5.0 g
Hydrochloric acid (10 per cent solution)	1 ml
Water to make	1000 ml

The method of compounding this bath is very important. Each of the solid chemicals should be dissolved separately in a small volume of water, the solution then mixed strictly in the order given, and the whole diluted to the required volume. If these instructions are followed, the bath will be pale yellow in colour and perfectly clear.

Toning will take from 2 to 10 minutes, according to whether the tone desired is a dull green or a pure blue. Half a litre of bath should tone about 4 sq ft of image, more acid being occasionally added if toning becomes too slow.

Ferric ferrocyanide is exceedingly susceptible to the action of weak alkalis. Long washing in ordinary water must therefore be avoided, and the precautions previously advised (§ 747) in regard to prints toned with uranium, viz., washing, clearing the whites, and dissolving the residual silver salts apply equally to iron toning.

However, an image which has been slightly weakened may be revived by a final rinse in an acid bath; an image which has been completely decolorized by an alkaline bath or by a cyanide solution may, after rinsing, be regenerated by means of a ferricyanide solution weakly acidified with hydrochloric acid.

749. Purplish-red Toning with Copper in Single Solution. Copper toning does not intensify the image; it even has a tendency to reduce slightly in the case of toning taken to finality and followed by removal of the residual silver salts.

For preparing the toning bath, the copper ferricyanide may be dissolved either in ammonia or ammonium carbonate, but the clearest colours and the purest white are obtained by using a solution of neutral potassium or sodium citrate as a solvent (W. B. Ferguson, 1900).

Neutral potassium citrate	40 g
Copper sulphate, 10% solution	35 ml
Potassium ferricyanide, 10% solution	30 ml
Water to make	1000 ml

The solution should be light green and perfectly clear.

Toning should require from 2 to 10 minutes approximately, according to whether the tone desired is a warm black or a purplish-red. Half a litre of bath should tone about 2 sq ft of image.

Copper ferrocyanide is not affected by alkaline solutions; consequently the precautions specified in the preceding cases for preventing the reduction of the image by the calcium bicarbonate in ordinary water are not necessary.

If the image is slightly weak it may be strengthened, after a brief rinse, in a solution of about 5 per cent of copper sulphate, to which has been added a little hydrochloric acid. This is followed by a second rinse.

The removal of the residual silver salts may be done in a neutral solution of sodium thiosulphate (hypo) about 10 per cent; but there is no disadvantage in using an acid solution.

750. Mixed Toning. Among the very numerous combinations possible in toning with ferrocyanides, the following may be particularly noted. A print, toned with uranium or copper in a single bath, may be immersed in a weak solution of ferric chloride (perchloride of iron) to which a little hydrochloric acid has been added. This must be before the treatment with hypo. This gives dark green or purplish tones.

A mixture may also be made of the iron and uranium toning solutions for obtaining, with a single bath, sepia, dull green or bluish-green tones, while a full green may be obtained in a single bath by a mixture of vanadium and iron.

751. Two-solution Ferrocyanide Toning. This method of working is used principally in toning with iron, which is here given as an example.

The print is first immersed in a solution of potassium ferricyanide, of about 5 per cent strength, which must be previously rendered alkaline by adding a little ammonia or sodium carbonate. This is allowed to act until the image is yellowish through its entire thickness.

A variation suggested by C. H. Bothamley (1918) obviates the employment of the ferricyanide, and consequently the combination of this salt with the gelatine. The image is first converted into chloride, e.g. by immersion in a hydrochloric solution of chromate or permanganate, and then converted into silver ferrocyanide by immersion in a solution of potassium ferrocyanide.

After washing until the whites are thoroughly clear, using the clearing bath already given

(§ 746) if necessary, the image is toned blue by immersion in a weak solution of ferric chloride.

Iron perchloride (standard solution 45° Baumé)	50 ml
Hydrochloric acid	10 ml
Water to make	1000 ml

After a quick rinse the print is immersed in an acid fixing bath, then well washed in slightly acidulated water.

752. Dye-toning: General Considerations. It was observed by A. Traube in 1906 that, after suitable conversion of the silver in a photographic image into silver iodide, this salt can fix *basic dyes* in a manner that may be compared to the fixation of colouring matters by means of mordants in dyeing.

The majority of artificial colouring matters known as aniline dyes can be divided into two categories, *basic dyes* and *acid dyes*.

A *basic dye* is a salt in which a base, bearing by itself the colouring power, but generally insoluble in water, is combined with a mineral or an organic acid—chloride, sulphate, acetate, oxalate, etc. All *basic dyes* are very soluble in alcohol: they have a marked affinity for colloid, but they will not combine with gelatine.

An *acid dye* is a salt of which the acid radical forms the essential colouring constituent, this acid dye being combined with a mineral base—salts of sodium, potassium, ammonium, and calcium. *Acid dyes* are, as a rule, insoluble in alcohol.

If solutions of *basic dyes* are mixed with those of *acid dyes*, an insoluble precipitate generally forms. On the other hand, dyes of the same character can always be mixed with each other for obtaining intermediate tints.

When a piece of blotting paper has its lower extremity dipped in a weak solution of a dye, the water rises on the blotting paper more rapidly than the colouring substance when this latter is *basic*, the coloured stain being thus preceded by a moist zone free from colour as the moisture rises. This phenomenon does not occur with *acid dyes*, and it forms a simple test for distinguishing between the two categories. Dyes intended for ordinary dyeing are mixed, as a rule, with inert soluble substances for the purpose of maintaining the colouring properties constant from batch to batch. The complete designation of a dye ought to include all letters or numbers following the name of the colouring substance, and the name of the maker. Dye substances of the same name but coming from different sources are not necessarily identical.

The mordanting can be carried out by the

formation of silver iodide and cuprous iodide using the intensifying bath described in § 551, due to G. Zelger, 1924. Dye toning by mordanting was applied to the preparation of tricolour transparencies by G. A. Richard in 1896, but his methods were not described.

After remaining a sufficient time in a weak solution of one of these dyes, a very intensely coloured image is obtained. The washing after immersion in the dye removes the colouring matter which has penetrated the gelatine without having the slightest affinity for it, but it cannot remove dye fixed on the silver iodide. The images thus obtained are, unfortunately, very opaque, and the silver iodide can only be removed after a complementary mordanting, otherwise the colouring matter, being no longer fixed, would be diffused.

This mordanting is best done by means of an acid dye of the same shade which will at the same time reinforce the image.

The use of various metallic ferrocyanides as mordants, suggested by R. Namias (1909-1911), has become a practical success through the publication by J. I. Crabtree (1917) of working details for dyeing images previously toned by the formation of ferrocyanide of copper (§ 749). An advantage of this method is the almost perfect transparency of this ferrocyanide in dry gelatine. It has since been found that ferrocyanide of uranium constitutes an excellent mordant (§ 747).

The mixture of silver ferrocyanide and chromium hydroxide obtained by bleaching in a solution of ferricyanide and potassium bichromate acidified with acetic acid may also be used (F. E. Ives, 1919). In all cases the silver ferrocyanide which constitutes the mordanting agent must remain in the image. This fact has been applied as a method of double toning (J. I. Crabtree and W. Marsh, 1931): partially tone in a single-bath iron toner (§ 748), stop toning, rinse, remove the silver ferrocyanide, rinse and complete the blue toning. The silver ferrocyanide, which is present only in the fraction of the image last toned, then plays the role of mordant and allows one to obtain shadows which are green, brown, or purple according to whether the dye bath contains auramine, chrysoidine, or safranin.

The most popular mordant to-day is cuprous thiocyanate (J. H. Christansen, 1917), since it is very transparent, practically colourless, and gives a strong image from one that was initially weak.

According to whether the conversion of the original silver image into a mordant is superficial or complete, the colours produced by the dyeing will be broken or pure.

For certain purposes, and notably for photography and cinematography in colours by the superimposition of two or three images in primary monochrome elements, it is essential that the image should be very pure and highly transparent. It is important, therefore, to start with very feeble images and to convert the whole image into a mordant which itself is without any appreciable colour.

The stability in daylight of images toned in this manner is very inferior to that of images toned by the formation of metallic salts. These processes answer well for motion picture films and stereoscopic or lantern transparencies. But they are scarcely suitable for window transparencies exposed to a strong light for any length of time.

The use of these methods of toning has for a long time been restricted to transparencies, but a working method has been introduced by A. and L. Lumière and A. Seyewetz (1925) for paper prints.

In the presence of organic solvents which do not affect the stability of the mixture, it is possible to mordant and tone in a single bath (J. I. Crabtree and C. E. Ives, 1929), but the choice of dyes is very limited and the operation somewhat tricky, so that it is not a very practical method.

753. Mordanting the Images. Unless very pure blues or greens are desired, mordanting may be done in either of the baths previously given for uranium toning (§ 747), or copper toning (§ 749). An essential condition, however, is that the silver ferrocyanide must not be removed by treatment with hypo. This would diminish considerably the capacity of the image for retaining the dyes. Broken colours, generally the most pleasing, are given by incomplete mordanting, toning being stopped when the image presents an almost imperceptible brown tint, which, with a new bath, will not require more than 2 minutes. The image must be washed between mordanting and dyeing until the whites are perfectly free from colour.

In the case of mordanting with uranium, the washing water must be acid. But any removal of the silver ferrocyanide must be avoided, as this plays as active a part as the mordant.

To obtain pure and bright shades (e.g. for

anaglyphs, three-colour prints, etc.) the following bath is recommended. Prepare only small quantities at a time.

Copper sulphate	20 g
Neutral potassium citrate	60-100 g
Acetic acid, glacial	30 ml
Ammonium thiocyanate, 10% solution	100 ml
Water to make	1000 ml

Add the thiocyanate, previously dissolved in a small quantity of water, a little at a time, the solution being shaken after each addition. When only required occasionally the thiocyanate should be added at the time of use. The bath should be discarded when it starts to deposit copper thiocyanate since this will produce a uniform fog all over the picture.

The citrate and acetic acid, since they do not enter into the reaction, do not become exhausted and a bath which has become slow-working may be revived by an addition of 10 g per litre of ammonium thiocyanate, providing it is still of a blue-green colour due to the presence of cupric salts. If it is almost decolorized, 5 to 10 g of copper sulphate should be added per litre.

The photographic material should not be allowed to remain in the mordanting bath after the transformation of the silver image is complete.

After mordanting, the image must be washed until the clear portions are perfectly free from colour. Double-tone effects can be got by dyeing, in one of the following baths, an image which has been toned to a blue in the bath recommended in § 748, but with the ammonium alum omitted. The shadows only are then toned to a blue: the light half-tones are bleached and they alone can fix the dye (Kodak Co., 1922).

754. Dyeing of Mordanted Transparencies.

Dyeing is effected in an aqueous solution of the dye, to 500 ml of which has been added from 1.5 to 9 ml of glacial acetic acid. The object of the acid is to prevent the dye from fixing on the plain gelatine. The quantity of this acid may be increased if the whites show any appreciable discoloration. The concentration of the dye may vary from 30 g to 25 g per litre of solution. A few trials will indicate the best concentration. Very concentrated solutions should be avoided for dyes whose colouring power is considerable, e.g. methyl violets and Paris violets, and also in the case of dyes, like safranine, which are not readily washed out.

Frames or clips should be used for immersing

plates or films in the dye baths; alternatively rubber gloves should be worn.

The following table gives various dyes with their corresponding colour and the group to which they belong. They are all well suited for dyeing with the mordants previously given.

Auramine decolorizes if warmed to 75°F and is therefore not very suitable for tinting transparencies which are to be projected.

COLOUR	DYE	GROUP
Warm brown	Chrysoïdines	Azo
Reds	Rhodamine B.**	
"	Rhodamine ** S.	Phthalein derivative
"	Safranines	Azine
"	Fuchsin*	Triphenylmethane derivative
Orange	Acridine orange	Acridine
Yellows	Auramine**	Diphenylmethane derivative
"	Phosphine	Acridine
"	Thioflavine**	Thiobenzoylic
Green	Malachite green*	Triphenylmethane derivative
Blue-green	Methylene green	Thiazine
Blue	Methylene blue	Thiazine
"	Victoria blue	Triphenylmethane derivative
"	Capri Blue**	
Violet	Methyl violets	Triphenylmethane derivative

* Dyes suitable for anaglyphs and two-colour photography.

** Dyes suitable for three-colour photography.

All the intermediate colours can be obtained by mixing these various solutions in suitable proportions, or by successive immersion in different baths with intermediate rinsing.

The dye absorbed by the gelatine may sometimes be destroyed, without destroying the dye adsorbed to the mordant, by immersing the image in a very dilute solution of bisulphate (A. Seyewetz, 1909), hydrochloric acid (L. Lobel, 1920), sodium hydrochlorite (R. Namias, 1936) or hypo, the latter solution being diluted with about its own volume of alcohol (W. Huse, 1926). A test should be made before applying these decolorizing agents in specific cases. Since the image colour is not always the same as that of the dyes mixture, because of the different affinities of the dyes for the mordant, it is wise to carry out preliminary tests.

According to the intensity of colour desired, and also according to the strength of the dyeing bath, immersion in the solution may vary from 2 minutes to about 1 hour.

After dyeing to the colour desired, the image

is washed in several changes of water for about 10 minutes. An image which has been coloured too deeply may be reduced in intensity by brief immersion in water to which a few drops of ammonia—about 1 millilitre per litre—have been added. An image which has been insufficiently dyed can be re-immersed in the mordanting bath after a brief rinsing.

In the case of an image where the silver has been only partially transformed into mordant, if the tone is considered to be too weak, then the transparency may be returned to the mordanting bath after rinsing, and the process repeated.

The plate or film should be swabbed before drying, since every drop of water will leave a mark. Varnishing will often increase the transparency of the image (§ 576).

755. Dyeing Mordanted Prints on Paper. After mordanting by the formation of copper thiocyanate in the bath of which the formula is given at the end of § 753, the prints made with extra wide margins should be washed for about 30 minutes in running water, or water frequently renewed. A print is placed with its back in contact with a sheet of glass a little larger than the print, or on the flat bottom of a dish, and surface-dried with a blotting board.

The dye is applied to the print by means of a large flat brush—cod-tail—or a plug of cotton wool, using always an ample excess of dye, which may be spread without any special precautions other than avoiding all contact of the dye with the borders or the back of the print.¹ By using solutions of sufficient strength the dyeing is completed in about 2 minutes.

The dye solutions to be used in this case are 1 per cent solutions of any one of the following dyes, with addition of 1 per cent glacial acetic acid—

Thioflavine T: Methylene Blue: Fuchsine:
Malachite Green: Methyl Violet

or a mixture of these solutions in suitable proportions.

The excess of dye should be drained off at one corner, and the print washed in running water until the slight tinting of the base does not get

¹ The back of the print may be protected from the dye by attaching it to a glass coated with rubber solution, and covering the margins of the print with strips of paper coated with the same rubber solution. Dyeing may then be proceeded with in a dish, but more dilute solutions should be used. After finishing and drying, the print is detached by being pulled from the glass; any rubber which may adhere is removed by rolling under the fingers.

any lighter. This will require from 30 minutes to an hour. On drying, this tinting decreases but does not completely disappear.

To clear the whites completely, the prints may be placed for 30 to 60 seconds in a 0.4 per cent solution of potassium permanganate, either neutral or acidified with 0.2 per cent sulphuric acid, quickly rinsed, and cleared in about 2 per cent bisulphite solution followed by a further rinse, then swabbed and dried. The decolorizing agents which have already been given for transparencies (§ 754) may also be used. When a mixture of dyes is involved, it sometimes happens that one of the dyes is acted on preferentially.

In the case of emulsions very strongly hardened to allow of drying by heat, any chemical treatment is generally unnecessary for bleaching if the washing is carried out in water at 120°F. The very slight tint remaining on the base does not show on the face of the print after drying (C. Rosetti, 1936).

756. Tinting. While toning affects the colour of the image only, the base remaining colourless, a general tinting is intended to colour the base itself, the image appearing in black, or in a colour, if it has been previously toned, on a tinted ground.

General tinting is done by means of acid dyes, generally those prepared for woollen fabrics, the fixation of which is facilitated by the addition of a little acetic acid—about 5 ml of a 10 per cent solution of the acid in 1 litre of bath. In order to avoid the softening of the gelatine by dyes, they should be employed in very dilute solutions. It is very exceptional that a strong colouring of the base of the image is desired.

By analogy to the case of wool, the acidic ion of the dye may be considered to combine with the basic groups in gelatine; conditions which tend to diminish the basicity (treatment with nitrous acid, hypochlorites, hydrogen peroxide, and all strong acids in relatively concentrated solution) also diminish the readiness to dyeing.

It should be borne in mind that this tinting diminishes the luminosity of the prints considerably; the loss is from 20 to 90 per cent; and it also lessens contrast to a marked degree.

The average time of immersion is 3 minutes for transparencies on plates or films. For prints on paper it must be appreciably less, and, in addition, it is desirable to use more dilute solutions. Prints on paper may be tinted chamomile in a very dilute infusion of tea or coffee or in

a permanganate solution. In the latter case the whites may be made to reappear by touching the swabbed print with a brush moistened with a dilute solution of bisulphite, followed by a quick rinse. Gelatine that has been hardened too much will only take the dyes irregularly.

After tinting, the prints or transparencies should be washed for several minutes to remove

the dye which adheres superficially to the gelatine and the support. Long washing, however prolonged, will scarcely reduce a tint which is too strong.

Before drying, the transparencies or prints should have all surface moisture removed. Any dye which may be discharged or remain in drops on the surface will cause streaks or marks.

CHAPTER XLII

WASHING, DRYING AND GLAZING OF PAPER PRINTS

757. Methods of Washing Prints. The part played by washing photographic emulsions on a permeable (paper) support, differs in no way from that in washing photographs on impermeable (glass) and practically impermeable (film) support, which has been studied previously (§ 507). The mechanism of washing, however, is slightly different, the salt concentration changes being considerably slower in the interior of the paper (fibres and sizing) than in the gelatine layer. Washing may be controlled by the same methods already indicated for plates and films. It has often been suggested that the efficiency of washing may be controlled by adding a colouring matter to the fixing bath or to the first wash water, such a material being eliminated at almost the same rate as the hypo. There is, however, always a risk, when applying this treatment to a paper on which this experiment has not already been tried, that the colouring matter may be ultimately retained by the paper or by the baryta coating. In general, this method is not advisable or necessary.

When a gelatine coating on an impermeable support is being washed, the concentration of the salt solution in the coating is reduced by a constant fraction of its former concentration after each change of water (§ 508), or at the end of equal periods of washing in running water (§ 509). The soluble salt is expelled sufficiently quickly for it to be necessary for the water to be renewed very rapidly. On the other hand, the diffusion of sodium thiosulphate and of soluble silver complex thiosulphate from a paper and its baryta coating is much slower, and is lessened as the quantity remaining to be eliminated becomes smaller. Under such conditions there is no longer any advantage in employing such a rapid renewal of water for papers as in the case of plates and films, the rate of washing being governed by the rate of elimination of salts from the support.

K. C. D. Hickman and D. A. Spencer (1925) have shown that this slowness in elimination during washing is a property of paper in the sheet form and not a specific property of its fibres. The diffusion through the cell walls is slower than that in plain water, and the period of time a salt takes to pass through a large

number of fibres in series is considerably increased by the resin sizing in the paper, for when the paper is calendered the resin melts, thus rendering the fibres partially impermeable and, at the same time, filling up the interstices. The same experimenters have shown that the treatment recommended by A. Charriou (1923) for hastening the washing of papers is based on a theory which is invalid. The process consists in submitting the prints, during washing, to the action of an inert salt, such as sodium bicarbonate, which would displace the hypo remaining in the paper; such treatment would only be efficacious in the case of an irreversible adsorption, and this does not occur.

In order to bring about practically complete elimination of removable salts, it is necessary that thin papers should be washed for 30 minutes and very thick papers (card, postcards) for 90 minutes, using running water or water which is renewed every five minutes. In the former case it is sufficient to employ moderately fast-running water, so long as the prints are moved about fairly frequently to prevent them massing together, which prevents the penetration and renewal of water. Clean water must have constant access to *both* sides of the prints.

When using running water for washing, it is preferable to make use of an arrangement which keeps the prints moving inside the receptacle. When washing in changes of water, it is essential that the prints be removed *one by one* from the dish of contaminated water and placed in the dish of fresh water. The removal of prints in a mass from one dish to another, or emptying and refilling a dish with the prints heaped together on the bottom, is absolutely ineffective.

An excellent method of hastening the elimination of salts retained by photographic papers consists in pressing-out the liquid with which they are saturated from time to time (Lumière and Seyewetz, 1902). For example, at each change of water the prints are gathered in a heap on a flat and rigid support, and the water pressed out with the hand, or, better still, by pressure with a roller (a wooden rolling pin or a thick round glass bottle can be used for the purpose). The prints, having been squeezed in this way, are replaced in the washing tank, which

has been emptied and refilled with clean water. When only a very small number of prints have to be washed, they may be pressed between blotting paper rather than treated as above.

758. Apparatus for Washing Prints. Print washers are often less efficient than plate washers, the prints usually tend to heap themselves up on the bottom of the tank or on the perforated false bottom. The use of floats provided with clips for holding the prints has often been suggested, but the use of such devices is hardly possible except when washing a very small number of prints, and in that case it is just as practicable to carry out the washing in several changes of water, transferring the prints, one by one, from one tank or dish to another.

When it is required to wash a fairly large number of small-sized prints, either a washing machine or a shallow cylindrical tank can be used, the latter being fitted with inlet pipes placed tangentially, so that a whirling movement of the water is produced. If a more suitable container is not available, a dish may be used, with a rubber pipe to bring the jet of water from the tap to the dish in order to avoid fractures in the paper which might occur if the prints were hit directly by the jet. A washing machine consists essentially of a perforated metal drum, the axle of which is mounted horizontally on bearings fitted to an overflow tank, in the inside of which it is kept rotating either by an electric motor or by the fall of the supply water on to the paddles of a water-wheel connected with the drum itself. A secondary flow of water is generally directed through the perforations to prevent the prints from sticking to the drum. With such machines there is often a risk of the prints becoming torn or creased if an attempt is made to wash large-sized prints, while prints on stiff supports are often scratched when washed by this method. Continuous washing machines are available for prints made on long lengths of paper, or for separate prints held between two endless belts or aprons of permeable material.

Another method for washing prints, particularly useful for large prints, in which the consumption of water is reduced, is the cascade washer. A number of tanks are arranged in tiers, the water flowing from one tank into the tank immediately below (arrangements should be made to prevent the prints being carried over by the current of water). When removed from the fixing bath, the prints are placed in the lowest tank and are transferred progressively

through the various tanks, so that systematic washing is ensured (the prints are moved in the opposite direction to the flow of water).

If the same set of tanks is used to wash the prints from several sets of printers, it is an advantage not to mix the different batches, thus simplifying the sorting of the prints after drying. In this case each batch may be identified, until after drying, by means of a piece of material numbered with indelible ink which accompanies the prints of each batch in the tanks and in the drying apparatus.

Before the prints are dried it is a good plan to remove all foreign matter (pieces of paper, particles of gelatine, dust, etc.) from the surface of the prints by wiping them with a large soft sponge (an ordinary or rubber sponge) which has been well soaked in water and squeezed almost dry. For this purpose, the prints may be laid on the flat bottom of a developing dish tilted against the side of the sink; at the same time, the greater part of the superficially adhering water is removed, and the time required for drying is thus shortened. This precaution is most essential in districts where the water supply contains large quantities of lime salts, which, during drying, are liable to form whitish streaks on the surfaces of the prints; if such lime deposits appear in spite of wiping over with a sponge, a small proportion of hydrochloric acid (1 per cent) should be added to the last wash water.

759. Drying of Paper Prints. The old method of drying paper prints was to hang them, by one or two corners, according to their size, with clips on to lines stretched either between the walls of a well-ventilated room, or fixed to a frame which is fitted to the wall or hung from the ceiling by cords passing over pulleys. When dried by this method, prints may tend to curl up or roll into small tubes, and the process of flattening them out involves an additional manipulation, during which cracks in the coating are sometimes produced. Prints may be flattened by passing the back of the print under the straight edge of a hard ruler, using a single continuous movement, as any hesitation generally produces a crease in the print. Also there are flattening machines in which the prints are inserted between two endless aprons passing at a fairly sharp angle round a return roller of very small diameter.

One can also proceed as follows. Place together two prints of the same size face to face; using a sponge, out of which as much

water as possible has been squeezed, the backs of the two prints are dampened and the prints afterwards placed between clean blotting paper; when a certain number have been piled up in this way, they are put under pressure in a copying press for a few minutes. It is true that the gelatine forming the support of the image could be kept moist by dipping the prints, before drying, in water containing a little glycerine, but if this remedy is applied the risks of deterioration of the image under the influence of impurities in the air is considerably increased. The method of drying prints by suspending them freely is therefore usually confined to prints on non-emulsion papers (such as salted papers, ferro-prussiate papers, etc.).

760. The usual method of drying papers coated with emulsion is to lay them emulsion downwards on a support which allows of free access of air, such as stretched linen, butter muslin, or galvanized wire netting. If necessary, drying may be hastened by a current of warm air. When the amateur has only a very small number of prints to be dried, they should be first pressed between blotting-paper, and then placed emulsion downwards on dry sheets of fluffless blotting paper. Blotting cards generally give much longer service and are therefore more economical in use; when not in use they should be protected from dust.

When a large number of prints are to be dried, a drying cupboard is generally employed. The cupboard is fitted inside with sliding frames covered with cloth or wire netting (the frames with wire netting should be kept for prints that have not been toned); if a sufficiently large number of supplementary frames are available, they can be filled with prints outside the drier and placed inside as the frames containing the dry prints are removed. Such a drier is sometimes fitted with a glass door, while the sides of the cupboard may be furnished with ventilation holes at the top and bottom, covered with fine gauze to keep out dust. The temperature of the air inside the cupboard is usually raised by electric resistance heaters and sometimes by gas jets under sheet iron; a fan may be used to accelerate the flow of air through the cupboard. A drier which is less bulky when not in use may be made by stretching between two vertical walls (partition walls, furniture, etc.) pieces of cloth, each piece being mounted on an automatic spring blind roller, so that it rolls up when the free end is released.

For the rapid drying of large numbers of prints continuous drying machines are often used; the prints are inserted one by one between two endless aprons or belts of porous fabric which are carried round a cylinder heated from the inside. The material generally used for the aprons is *swansdown-calico*, one side being smooth, the other fleecy, such material being specially made for covering the cylinders of printing machines. At the end of the travel the prints emerge dry and fall into a box placed in position for the purpose. (C. Jellinek, 1908).

In drying machines in which the prints are successively carried round two cylinders in opposite directions, creases are often produced as the direction of motion is changed, especially in the case of very large prints.

Postcards may be dried by fitting them into wooden grooves, the distance apart of the grooves being slightly less than the length of the card. The cards are then placed in the grooves so that the coated side is convex, thus counteracting the tendency of the card to curve in the opposite direction.

761. The gelatine of positive-paper emulsions is usually sufficiently hardened to be able to resist relatively high temperatures without damage. However, it should be remembered that there are certain papers, particularly glossy papers, (the gelatine of glossy papers is usually only slightly hardened, so that they can be "glazed" if desired) which cannot be dried emulsion downwards, particularly if a hot drier is used, without a previous hardening (alum) bath (§§ 460 and 701). Prints intended for the bromoil processes must never be hardened with alum. They may be dried by laying them on a pad of blotting paper and fixing the corners with clips or drawing pins.

The operation of hastening the drying by heat often brings about a modification in the tones of prints on print-out paper and on prints which have been developed or toned to warm tones; it nearly always causes a slight alteration in the appearance of the surface, so that when quality is more essential than speed, methods by which the prints are dried in less than half-an-hour should be avoided.

Prints should be removed from the driers before the gelatine becomes over-dried, especially if the drying is hastened by a current of warm air, as the gelatine tends to become brittle and curling of the prints is only prevented with great difficulty. Immediately the prints are dry,

but while they are still supple, they should be piled up on top of each other, and can be slightly weighted without any risk of their adhering to each other. Special care should be taken to place all the prints of the same pile the same way up, i.e. facing in the same direction, otherwise, if the drying has not been quite sufficient, two prints with the emulsion surfaces in contact would stick together.

762. Rapid Drying of Prints. In cases where prints have to be delivered in a great hurry, the rate of drying may be considerably increased if the print is immersed for a few minutes in a bath of methylated spirits (§ 520) after the final wash water. When the water has been displaced by the spirit throughout the thickness of the paper, a fact which can usually be verified by the translucent appearance presented by the paper when examined from the back, the prints are squeezed to expel the alcohol and pressed between blotting paper; they are then dried by heat, using the drying apparatus at its maximum temperature.

When only a very few prints have to be dried in the shortest time possible, they may be bathed in alcohol, pressed almost dry between blotting paper, and then singed one by one. For this purpose, the print is held by a lower corner in an almost vertical position, the upper corner being held to a blue gas flame, or to a match; the alcohol with which the print is still impregnated will then burn, the flame gradually creeping down the print. When it arrives about half-way the print is quickly turned round, taking hold of the corner at which the alcohol was originally lighted, with the free hand. The flame then spreads upwards until it reaches the corner which was originally held in the hand. When the operation is properly carried out there is no risk of burning either the print or the fingers.

763. Deformation of the Image during Washing and Drying. All papers tend to stretch when wetted and to contract during drying, the final dimensions being usually less than the initial dimensions. In the case of machine-made papers—and photographic papers usually come within this category—the variations in length and breadth are not proportional to the original dimensions of the piece of paper. In such papers the fibres tend to lie in a direction parallel to the length of the band of paper, so that although the fibres themselves swell when wetted their length remains practically constant. To determine the direction of the fibres of a paper a

small disc is cut out of it and floated on water (in the case of papers coated with an emulsion the plain side of the paper should be in contact with the water). If this is done the paper is seen to curve inwards in the form of a portion of a cylinder; the direction of the fibres, that is, the direction in which the dimensions are practically constant, is that of the generators of the cylinder, i.e. the straight direction.

The expansion which occurs when the paper is wetted, and which varies from one paper to another, and even for the same paper dried to the same extent, may amount to 2.5 per cent of the width of the paper and 0.5 per cent of its length. When dried with free access of air, the contraction, relative to the initial dimensions, may attain 1 per cent of the width and 0.5 per cent of the length. When the same paper is alternately wetted and dried several times, similar variations occur each time, their magnitude often being slightly greater but soon reaching a limit.

In ordinary photographic practice, these variations in the dimensions of photographs were particularly important at the time when photographs were mounted by the wet process; the prints were fixed in position by the mountant when expanded to their fullest extent, appreciable deformation thus resulting. In that case, one endeavoured to place the subject in relation to the paper in such a way as to minimize the effect of the deformation, for example, by lengthening a very stout sitter, or broadening a person who was rather thin. The use of dry-mounting processes, has now allowed the deformation of the image to be sufficiently reduced so as to be no longer a source of difficulty in purely artistic work.

In all cases where measurements have to be made on photographic images, paper prints are usually avoided. If, however, great accuracy is not essential, two scales may be printed on the margins of the sheet of paper, parallel to two adjacent sides, and measurements relative to these scales may be taken.

For work requiring precision, paper coated on the back with plain gelatine may be used. Before printing, the paper is expanded by soaking in plain water for some time, and is then laid emulsion upwards on a sheet of plate glass; any air bubbles and excess of water are expelled, and the whole is then left to dry. Owing to the adherence of the gelatine, the paper remains fixed at its maximum distension. When developed and dried, the image will have

exactly the same dimensions at the latent image (H. Roussilhe, 1922).

764. Glazing and Enamelling of Prints. The processes of glazing and enamelling, when applied to prints on glossy paper, considerably increase the clarity of the details of the image.

The enamelling process, which was formerly applied to prints on albumen or collodion paper is no longer used. A sheet of flawless plate-glass was thoroughly cleaned, dried, and coated with a layer of an approximately 1 per cent solution of collodion. When the collodion had set, a solution of gelatine was run on top, and the print applied emulsion downwards on the gelatine solution, the excess being removed with a flat squeegee. A sheet of stout paper was applied to the back of the print by the same method, and turned over to allow the weight of the glass to keep the whole in place. When thoroughly dry, a cut was made with a penknife, and the print could be removed coated with a layer of collodion as highly polished as the plate-glass on which it has been moulded.

Similar results, although not as lasting, are obtained more simply by glazing prints on gelatine-coated papers. The print is applied while wet to a sheet of plate-glass, polished celluloid, or a piece of japanned iron plate (ferrotype plates). If the operations have been correctly carried out, the prints may be detached quite easily when completely dry. The gelatine surface is then as glossy as the support with which it had been in contact, but if damped afterwards at any time it loses its glaze.

An essential condition for the success of the operation is the absolute cleanliness of the glazing sheet, which must therefore be thoroughly washed in plenty of water whenever seen to be dirty. The cleaned and dried sheets of plate-glass are polished with talcum powder (French chalk), the excess of powder being removed. Ferrotype plates are polished with a flannel on which a few drops of a thin polish have been poured, and then finished off with a dry pad of flannel or chamois leather. (A suitable polish is prepared by pouring about 50 g of paraffin, white wax, or spermaceti—melted by holding it against a hot iron—into 1 litre of crystallizable benzene or light mineral petroleum. Plate-glass, as well as ferrotype plate, is sometimes polished with a pad of cloth on which a little very dry white soap has been rubbed.)

A glazing or stripping solution, in which prints are soaked for a minute or two immediately before being laid on the glazing sheet may be

used. Such a solution consists usually of purified ox-gall. This evil-smelling product can be replaced by its active constituents sold under the name of industrial biliary salts (a mixture of about 75 per cent of glycocholate and 25 per cent of taurocholate of sodium) to be used in aqueous solutions at concentrations of from 0.5 to 1 per cent, or (A. Seyewetz, 1936) by all other substances reducing the surface tension of the water such as wetting agents or solutions of about 1 per cent strength of various sulphonated fatty alcohols (Ocenol, Lorol, Igepon, etc.).

Immediately they are washed, the prints are applied emulsion downwards on the polished surface of the plate-glass or the ferrotype plate, which is placed flat on a table. (In very hot weather the risk of the prints adhering to the support completely is lessened by first allowing the prints to dry and afterwards wetting them by a short immersion in plain water before glazing.) After covering with a piece of cloth or parchment paper which has been previously wetted, bubbles of air and the excess of water are expelled with a *soft* rubber roller or a squeegee, working from the centre towards the edges. Any excess of moisture is then removed from the back of the print with blotting paper, and the whole allowed to dry by itself. The process of drying may be accelerated by placing the sheets in a warm oven. Trays, linen sheets, or sheets of clean paper should be placed so as to receive the prints should they detach themselves spontaneously.

When large-size prints are being glazed it happens that the corners, being the first to dry, loosen spontaneously, so that the image has iridescences at the edge of the parts prematurely freed. As glazing plates are placed horizontally each corner can be weighted with a small piece of metal, or the drying of the corners can be retarded by laying on them pieces of wet blotting paper.

When large numbers of prints are to be glazed, glazing machines may be employed; these resemble drying machines in their general design. The prints are placed emulsion upwards on an endless belt which applies them against a chromium-plated cylinder. The drum is heated, usually by electric resistances, from within, and slowly rotates, so that prints may be continually fed on to the machine.

The prints must not be too wet if they are to be glazed by heat, for the water evaporating between the hot metal and the gelatine coating

can leave mat spots. The best results are obtained with machines fitted with a device for polishing the cylinder at each revolution, so as to remove traces of gelatine or salts from the water remaining from previously treated prints. If this is not done mechanically, it is easily done by hand, and is necessary for the best results. When the water contains much lime the acid to be used in the last wash water is acetic acid which is almost inert as regards chromium-plated surfaces.

Prints glazed at an excessive temperature often lose contrast and undergo a change in colour tending towards yellow. The finer the reduced silver the greater these changes are. These phenomena are sometimes accompanied by the beginning of reticulation.

765. Facing the Prints with Cellophane. The

picture surface of a photographic print can be protected by a transparent sheet of Cellophane (regenerated cellulose) of the kind used for packing some food products. A sheet of Cellophane is distended by immersion in cold water for at least 5 minutes and is then applied to a glazing sheet. A print that has not been hardened is applied with the emulsion surface against the Cellophane. (In the case of a hardened print the gelatine is softened by immersion for about 10 minutes in tepid water, which should be warmer the harder the paper.) The whole is kept under pressure beneath some sheets of blotting paper until the next morning, when it is lifted by a corner and trimmed (J. L. Sheldon, 1931). Before removing the print from the glazing sheet a cloth may be pasted on the back of the paper.

CHAPTER XLIII

THE PRINCIPAL FAILURES IN MAKING POSITIVE PRINTS ON SILVER PAPERS

766. Preliminary Note. Before enumerating some of the failures which may occur in the various stages of the production of positive prints, the reader should realize that the great majority of failures are entirely due to mistakes made, often unconsciously, by the worker himself (§ 522).

The failures already described in connexion with the production of the negative need not be repeated here, but they apply as such when printing on development papers.

It should also be borne in mind that any defects in the negative are necessarily reproduced on the positives made from them, and are even occasionally exaggerated to a certain extent.

767. Failures Common to Various Printing Processes. *The Outlines of the Image are Doubled.* The printing paper has shifted in relation to the negative during printing. This occurs with print-out paper as a result of insufficient pressure during inspection of the image while printing.

Lack of Sharpness in Parts of the Image. Localized defective contact between the negative and the sensitive material, chiefly caused by warping of the back of the frame or printer, badly-fitted hinges, inequalities in the thickness of the cloth or felt with which the back is covered, or, in the case of transparency plates, by imperfect flatness of the surfaces in contact. The effect of defective contact is exaggerated by printing in diffused light and lessened if a point-source of light is used.

General Lack of Sharpness. The negative has been placed in the frame or printer back to front, the positive material being in contact with the support. The picture is then reversed. The thicker the negative, the more marked is this defect; it is lessened if the printing is carried out with a point-source of light in a fixed position relative to the negative.

No Image Appears, or only Very Faint after a Long Time. The back of the sensitive paper has been placed in contact with the negative.

Light Spots of Irregular Shape. Light or white marks may be caused by a shadow thrown on the frame during printing, by the presence of foreign bodies (pieces of paper, bits of the cloth or felt of the pressure pad, etc.) between

the glass support and the negative, or between the negative and the paper, or by opaque spots (fragments of gelatine, etc.) on the back of the negative.

Cracks in the Paper or Sensitive Coating. The prints have been rinsed or washed under a too violent jet of water, or the wet prints have been handled incorrectly. Large sheets of paper should be lifted by one corner, and the strain taken off by lifting also the opposite corner. A print should never be held by the middle of one of its sides.

White Spots Appearing During Fixing. Local solution of the silver image by particles of rust suspended in the fixing bath (especially in a used bath) due to iron or cast-iron pipes or to the vessels (iron casks, etc.) used for the storage and handling of hypo.

Blisters. Blisters which occur during the manipulation of paper prints consist of pockets of gas or liquid between the actual paper and the layer of emulsion. The first can be caused by transferring prints on development paper from a developer which is very rich in carbonate to a very acid stop-bath or fixing bath *without intermediate rinsing*. They may also be formed by using water supersaturated with air (very cold water under high pressure), which, on attaining the temperature of the atmosphere, liberates the excess of dissolved air in the form of bubbles in the substance of the paper. Blisters, which consist of pockets of liquid, are usually formed during the washing which immediately follows fixation in a very concentrated bath, especially on papers coated with insufficiently tanned gelatine, the water penetrating into the gelatine faster than the thio-sulphate solution can get out. Any factors which tend to weaken the gelatine locally, increase its permeability, or lessen its adherence to the support (contact with warm hands, folds, kinks, and creases in the print), favour the formation of these blisters. This tendency can be reduced by properly tanning the gelatine before or during fixation (the use of alum is effective even for collodion papers, as it hardens the gelatine of the baryta coating), and by avoiding very sudden changes of temperature and concentration in the handling of the prints.

When blisters have occurred, the paper at the back of each blister should be pierced with a fine needle, or, in the case of gelatine prints, and if the washing is finished, they should be placed in a bath of equal volumes of water and denatured alcohol, finally soaking in pure denatured alcohol.

Sticking of Gelatine Prints to Glass or Ferrotype Plates. The glass or ferrotype slabs were not properly cleaned, or the gelatine was excessively swollen when putting prints on the plates (insufficient tanning, washing in water which is too warm), or the prints (on the plates) were dried at too high a temperature.

Mat Patches on Glazed Prints. These patches, small and circular, or large with irregular outlines, are due to bubbles of air which were not expelled when laying down the print, and thus have prevented contact between the gelatine and the polished surface. When glazing on plate-glass, these air bubbles are easily visible through the back of the glass, as they form patches which are more glossy than the parts where there is perfect contact. If the print is examined in this way, after it has been put on, such bubbles can be easily expelled at the time, or the print applied afresh after re-wetting it.

Gradual Deterioration of Prints. A slow deterioration of prints may be due to bad fixation or insufficient washing. In the two following paragraphs the nature of such changes on print-out papers and on development papers is considered. In addition to these causes, changes in the image may be due to impurities in the mounts and in the mountants themselves (the presence of hypo in the pulp of the mount; acid glues to which hygroscopic materials have been added).

768. Failures with Print-out Papers. Bronzing of the Shadows. The formation of a reddish-brown or metallic film on the dense parts of a print on print-out paper (particularly on colloidion papers or papers very rich in silver) is usually due to printing from a very contrasty negative and attempting to obtain details in the high-lights, the shadows being consequently considerably over-exposed. If the metallization is not very pronounced, it often disappears during toning and fixation, especially when the treatment used brings about a marked weakening of the image (this does not occur with self-toning papers which have been treated with a salt bath). The metallic bronze on a print is often reduced by treating the surface with a wax or paraffin polish (A. Steigmann, 1925).

The Image as a Whole Refuses to Tone. This occurs only with separate toning baths, when the gold is exhausted, or when various impurities (hypo, sulphite, etc.) have gained access.

Parts of the Image Refuse to Tone. The parts which refuse to tone are not wetted by the solution owing to the presence of greasy spots (irregularly-shaped marks due to finger-prints) or circular spots due to air bubbles.

Brown or Black Stains. Local formation of silver sulphide by contact with traces of hypo from the fingers or a badly-washed dish.

Patchy Tones on Prints. The prints have adhered to each other during the toning or, when toning and fixing in separate baths, the prints have not been washed (or insufficiently washed) before toning.

Reddish Prints on Self-toning Papers. Too long washing before fixing. Self-toning papers should not usually be washed before fixing (or before treatment with salt solution), as washing removes the necessary toning materials.

Prints are too Pale when Fixed. Printing has not been carried far enough through failing to take into account the loss in depth which nearly always occurs, but to an extent which varies with the paper and the treatment used.

Pinkish Stains on the Dry Prints. These are generally caused by alkaline dust falling on the print while it is still damp. Powdered chemicals should always be handled and weighed out away from the place where processing operations are carried out. Such stains sometimes disappear if the print is washed in water which has been slightly acidified with hydrochloric acid, followed by a brief rinse in pure water.

Loss of Tone During Glazing or Dry Mounting. The print has been heated to too high a temperature.

Gradual Fading of the Image after a Time. If the light tones become greenish or yellowish, it is usually due to the use of a combined toning and fixing bath containing no gold, or used after the gold had become exhausted, toning then being entirely due to sulphiding.

Gradual fading of the image is generally caused by incomplete removal of the hypo, which, under the influence of the oxygen and moisture of the atmosphere, gives rise to sulphuric acid, which attacks the silver image. A gradual discoloration of the whites of the print is usually due to incomplete fixation (use of an exhausted fixing bath).

769. Failures with Development Papers. General Fogging of the Image. General fog may

be caused by storing the paper under bad conditions; by omission of the bromide from the developer (in these two cases, the margins are usually fogged); by wrong adjustment of exposure to development; or by printing a soft negative on an insufficiently contrasty paper, the working conditions having been adjusted with the object of obtaining full blacks in the shadows of the picture.

The Image has Detail but no Strength. Printing a soft negative on an insufficiently contrasty paper, the conditions having been adjusted to obtain pure high-lights.

Grey or White Streaks. Too long development of an under-exposed print; paper kept in a damp place. With gaslight papers, white or light-coloured markings, especially if the paper is damp, may be caused by using a developer containing an insufficient quantity of carbonate.

Mottling: Uneven Density of the Image. Considerable under-development of an over-exposed print; paper kept in a damp place.

Greenish Blacks. Insufficient development in an attempt to compensate for over-exposure or, on chloride papers, an unsuitable developer formula.

Yellowish or Brownish Tones. Over-exposure, excess of bromide in the developer, or the use of an exhausted developer.

Brown or Black Stains. The paper has been touched with fingers impregnated with hypo, or has been placed in a dish which has been used for fixing and not properly washed afterwards.

Yellow or Brownish Stain on the Margins and Whites of the Image. These stains are caused by the oxidation products of the developer in a stale developer or in a neutral fixing bath in which developer from previously-fixed prints has accumulated. Local staining by oxidation products of the developer can arise from parts of the image not being completely immersed in the fixing bath. They may also be caused by silver which has been reduced in a very finely-divided state by the same process which leads to the formation of dichroic fog (§ 525) on negatives or transparencies, when too warm a developer or a developer which is too rich in sulphite is used (particularly on chloride papers), or by attempting to force the development of an under-exposed print.

Small Light Spots with Sharp Circular or Oval Outlines. Air bubbles adhering to the paper during development.

Black or Dark Spots. These spots often occur

on a print which has been fixed face downwards, and under which air bubbles have been imprisoned. Access of the fixer is obstructed, and the developer absorbed in the gelatine coating allows development to continue in these parts.

Powdery White Deposit on the Dry Prints. The use of wash water containing much lime (in this case, finish off the washing with a little "soft" water, i.e. boiled or spring water); or the prints have been fixed in a bath containing alum in which precipitation of aluminium sulphite has been caused by neutralization of the bisulphite. This deposit will disappear if the print is left in a 5 per cent solution of anhydrous sodium carbonate for some time, and then washed in pure water.

Bloom or Bronzing of Shadows in an Old Print. Slow action of the hydrogen sulphide (which is always present in small proportions in the atmosphere of towns) on the silver of the image. The print should first be cleaned, if necessary, by gently rubbing it with a wad of cotton wool soaked in petrol, followed by alcohol. It is then washed and sulphide-toned (§§ 736-41).

Yellow, Brown, or Purplish Spots appearing after Some Time on the Finished Print. Such stains, which are caused by incomplete fixation, may consist of silver sulphide formed from the silver thiosulphate left in the gelatine, or may be due to coloration, by light, of the silver chloride or bromide which has not been removed in parts of the coating, being protected from the action of the fixer by air bubbles or by adherence of prints which have not been kept moving sufficiently during fixation.

Gradual Bleaching of the Image, Starting in the Light Tones. Formation of yellowish-white silver sulphide, usually due to hypo left in the gelatine by incomplete washing; sulphur deposited in the gelatine by a decomposing fixing bath (milky bath); presence of hypo in the pulp of the cardboard on which the print has been mounted combined with action of atmospheric hydrogen sulphide. It is sometimes possible to restore such prints as follows. Clean them with a tuft of cotton-wool soaked first in petrol and then in alcohol; then place in a fixing bath containing alum, and wash thoroughly. If the lights are slightly stained brown or yellow by silver sulphide as a result of the slow decomposition of the silver thiosulphate remaining after bad fixation, they should be left for some time in a 2 per cent solution of potassium or sodium cyanide and again rinsed. Next, treat

the prints with a solution containing potassium permanganate (0.1 per cent), hydrochloric acid (1 per cent), rinse briefly, and re-develop the image in full light, finally washing in several changes of water.

770. Failures in Sulphide Toning. Yellowish Tones. The print has been insufficiently developed, usually following over-exposure. Occasionally such photographs can be saved by gold toning (§ 742).

Weak Prints, especially in the Light Tones. When bleaching with ferricyanide, the print still contained a little hypo (insufficient washing), thus forming a reducer; or sulphiding has been carried out in a sulphide solution which was

exhausted or oxidized and partially converted into hypo.

Blisters. The use of too strong a sulphide solution, or too prolonged treatment in a solution of the usual strength, the gelatine being considerably softened thereby.

Blue Spots. Formation of prussian blue by the action of the ferricyanide of the bleaching bath on particles of iron from water supplied in rusty pipes; or, more rarely, on the iron particles existing in the paper pulp or in the baryta coating. These spots may be removed, after sulphide toning and washing, by immersion in a very weak solution of ammonia, followed by brief rinsing.

CHAPTER XLIV

PRINTING PROCESSES BASED ON THE SENSITIVITY OF IRON SALTS

771. General Notes. The ferric salts of organic acids (oxalate, tartrate, citrate, etc.) are reduced to ferrous salts when exposed to light. Potassium ferricyanide is likewise reduced to the ferrocyanide by the action of light. A considerable number of photographic processes based on these reactions were pointed out by Sir John Herschel (1842) and have been perfected since then by numerous photographic workers.

Any reagent which will differentiate between ferric and ferrous salts can be used to convert the barely visible image formed by the photochemical reduction into an image which is very easily visible. The following table indicates some of the reagents commonly employed for this purpose.

	Ferric salts	Ferrous salts
Potassium ferricyanide	—	Precipitate of Prussian blue
Potassium ferrocyanide	Precipitate of Prussian blue	White precipitate
Tannins, gallic acid	Bluish-black precipitate	—
β -naphthoquinonesulphonic acid	—	Brown precipitate
Silver salts	—	Black precipitate of reduced silver
Platinum, palladium salts, etc.	—	Black precipitate of reduced metal
Gelatine, gum arabic, etc.	The colloid is rendered insoluble	—

In all cases where the differentiating reagent gives a coloured precipitate with the ferrous salt only, the reagent can be mixed with the ferric salt before sensitizing the paper, the reaction then taking place partly during the exposure to light and partly in the first wash water (or in a common solvent of the salts used). A positive image is obtained in this way if the print is made under a negative. If the differentiating reagent forms a coloured precipitate with the ferric salt, it should be used separately as a kind of developer in which the print is placed without intermediate washing. In this way a positive picture is obtained when the print is made under a positive.

A large number of other processes have been suggested which make use of the ability of ferrous salts to reduce various metallic salts (copper, mercury, gold, etc.). There are also those processes which are based on the differential actions of ferricyanide and ferrocyanide on various metallic salts (uranium, etc.). This last

reaction has already been used in certain toning processes as applied to silver images (§§ 745-50).

Papers sensitized with the various iron salts are very susceptible to the influence of damp (fogging, loss of sensitivity, etc.), and should therefore be kept in a very dry atmosphere.

Papers sensitized with iron salts are printed in daylight or by a powerful artificial light (arc lamps or mercury-vapour lamps).

THE FERRO-PRUSSATE PROCESS

772. Commercial Photoprinting Papers. Ferro-prussiate papers and cloths are still used in considerable quantities, for making blue-prints from engineers' and architects' drawings in spite

of the growth of the diazotype process (§ 839). They are sold in 10 to 20 yard rolls of thirty inches or forty inches width and are manufactured on machines which impregnate the surface of reels of paper with an aqueous solution containing a salt of iron together with a soluble ferricyanide or a mixture of the latter with a ferrocyanide. The printing speed of the sensitive paper so produced may vary according to the purpose for which it is to be used. In general, however, the depth of the colour of the resultant image decreases as the printing speed of the paper increases.

Ferro-prussiate papers are usually sensitized with ferric ammonium citrate or with ferric ammonium oxalate. The latter salt is to be preferred for most types of paper, partly because it has a high photo-sensitivity, and partly because the concentration of ferric ions in solutions of this salt is low, and may be reduced still further by the addition of a soluble oxalate. The use of a substantially non-ionized

iron salt in the sensitizing solution results in a reduced tendency to premature reduction during coating and drying of the sensitized paper.

Although ferricyanides are sensitive to light, the ferric salts employed have a sensitivity so much higher that the ferro-prussiate process may safely be said to be based upon the photosensitivity of the ferric salts alone.

When ferro-prussiate paper is exposed to a source rich in blue and violet (sunlight, carbon arc, or mercury vapour discharge tube) there is an immediate change in colour from pale yellow or green to blue, the depth of colour developed for a given duration of exposure and concentration of sensitizing salts being dependent upon the humidity of the paper. Upon further exposure the blue colour bleaches and the paper becomes white.

It is probable that the first action of light is to reduce some of the ferric salt to the ferrous condition, in which state it then reacts with the ferricyanide to form Prussian Blue, (ferric ferrocyanide). With commercial papers where the ferric salt is in considerable excess of the molecular equivalent of ferricyanide, continued exposure to light results in the formation of further ferrous salt which probably reacts with the Prussian Blue first formed to produce white ferrous ferrocyanide with the regeneration of ferric salt.

The initial Prussian Blue image is somewhat soluble in water, more so in the presence of mild alkalis and of phosphates. Upon this observation is founded a class of quick printing ferro-prussiate papers in which a proportion of the ferricyanide in the coating solution is replaced by some ferrocyanide under conditions where the Prussian Blue, formed by reaction between the ferrocyanide and the ferric salt, remains in solution. Papers coated with these mixtures are greenish-blue to blue in colour before exposure. They are quick printing, because the initial period of exposure in which the Prussian Blue image is formed has been eliminated.

Printing (the production of *photo-copies*) is carried out by exposing to light the coloured surface of the sensitive paper, which has been placed in contact with the back of the tracing. When very large tracings have to be printed, or in a drawing office which turns out large numbers of prints, continuous printing machines are used. In such machines, an endless belt carries the tracings to be printed, together with a band of ferro-prussiate paper, round a glass

cylinder, which is illuminated from the inside. The paper is washed by jets of water, arranged on the same or on a separate machine, and finally dried between endless canvas belts passing round one or more heated cylinders.

When the washing is carried out sheet by sheet in a dish, it is advisable to do so in three or four washings, taking about 10 minutes in all. The first wash water, which very quickly becomes turbid with excess of salts, should be thrown away almost immediately. A process which eliminates the washing of ferro-prussiate prints has been developed on a commercial scale in recent years. Prints are damped in a machine, similar to that used for the development of diazotype prints by the semi-wet process, with a solution containing a soluble salt of a metal (such as zinc) having an insoluble ferricyanide, together with a substance or substances capable of converting the sensitizing iron salt into a light-insensitive condition.

Unless the print is greatly over-exposed or reversed, the image appears in white lines on a blue background as soon as washing is commenced. Water which contains large quantities of calcium salts causes the formation of a deposit of yellowish basic iron salts on the image, and at the same time the image is weakened by their alkalinity, the weakening becoming more pronounced if the washing is prolonged. These defects may be remedied by carrying out the final washing in water which has been acidified with a little hydrochloric acid, which lightens the whites and strengthens the blues of the image. This acid must on no account be added to the first wash water, as it causes the formation of a general blue fog. Hydrochloric acid treatment and the treatments mentioned below cannot be carried out in zinc dishes, as the metal is very rapidly attacked.

Over-exposed prints, in which the lines are more or less strongly blued, and prints which have undergone reversal, in which the lines are darker than the ground, may be restored to a normal condition by treating with an oxidizing solution (a very weak solution of hydrogen peroxide, sodium hypochlorite, potassium bichromate, persulphate, chlorate, etc., neutral or slightly acidified). Such treatment should be deferred until after the second washing at least, and should be followed by washing in several changes of water.

If no drying apparatus is available, the prints are hung on lines of cord or string, or are laid out on muslin-covered drying frames.

Most types of ferro-prussiate paper yield prints which darken considerably during drying, owing to atmospheric oxidation of the ferrous ferrocyanide formed on full exposure. Prints which have been intensified during washing by means of an oxidizing agent do not show this effect.

Blocking-out is done with a paint-brush, using prussian blue water-colour. White lines are added with a pen dipped in a 20 per cent solution of neutral potassium oxalate, thickened with a little gum arabic (a 5 per cent solution of oxalic acid can also be used, but it causes rapid corrosion of the nibs). Parts retouched in this way should be washed or at least briefly rinsed (with the help of a sponge), otherwise the blue colour is liable to re-appear after a time.

As perspiration is always alkaline, one should avoid touching the dry prints with moist hands. The hands can be conveniently dried with talcum powder (French chalk) if necessary.

Ferro-prussiate prints fade if exposed to bright light for a long time. They can be restored by keeping in the dark, especially if the atmosphere is damp. Fading is most pronounced if the prints have not been fully washed and therefore contain traces of ferric salts.

A large number of methods have been suggested by means of which ferro-prussiate paper can be toned in various colours. The results obtained are usually disappointing.

773. True-to-scale Process. A process originated by F. and J. Dorel (1900) allows a relatively large number of copies (up to about 20) to be obtained from a ferro-prussiate print, the latter being used *immediately after its removal from the printing frame, and without washing*. The lines are produced on a white base in greasy inks of any desired colour, and the prints are free from the distortions and deformations which occur when a paper is wetted and dried.

For the purpose a jelly is used (consisting of a strong solution of gelatine to which some glycerine, ferrous sulphate,¹ ox-gall, an anti-septic, and a yellow or white pigment have been added), which, after it has been melted on a water-bath, is run in a layer about $\frac{1}{16}$ in. thick on to a wooden slab covered with thin, well-stretched zinc which has been roughened with glass-paper to facilitate adherence. When

the jelly is properly set, it is ready for printing.

The prints to be used for the purpose should be made on slow ferro-prussiate paper sensitized with a comparatively concentrated mixture in which the ferric salt should be in excess, giving clean and vigorous images, while over-exposure, and especially reversal of the image, should be avoided.

The print from the printing frame is carefully laid face downwards on the surface of the gelatine mixture with one application, avoiding air-bubbles and creases; good contact is assured by gently rubbing with a large pad of soft rags. After remaining in contact for about a minute, the paper is lifted off, and the gelatine quickly inked over with typographic or copper-plate ink, spreading it with a gelatine roller of the type used in letterpress printing. The ink adheres only to the parts corresponding with the lines of the image. The markings caused by creases, breaks, or stains on the tracing can be cleaned off with a damp sponge if necessary. Printing should be done on a well-sized paper, pressure being applied with a pad or a roller when the paper has been applied to the inked surface. After the paper has been removed, the ink can be dried with French chalk if the print is required for immediate use.

Normally, the gelatine is kept moist by the glycerine, and will not take the greasy ink. When the ferro-prussiate paper is applied, the excess of ferricyanide in the parts protected by the lines on the tracing is absorbed by the damp gelatine with which it is in contact, and, reacting with the ferrous salt, forms a blue line. The Prussian Blue, formed in this way, brings about tanning of the gelatine, which is then able to retain the greasy ink.

Any corrections or alterations can be made on the image before it is transferred to the jelly. Lines which are to be erased can be covered with a solution of gum arabic; parts of the design which require modification can be covered with a print from a rectified tracing, using suitable register marks. If desired, the prints can be made on tracing paper, in which case the ink is reinforced with powdered bronze, which only adheres to the inked lines. Transfer inks can also be used for printing in conjunction with special papers which allow of the inked image being transferred to stone or zinc by the ordinary lithographic processes; this method is used if a large number of copies have to be made.

Printing having been done, the jelly is washed with a wet sponge to remove the adhering ink,

¹ For occasional use, the addition of ferrous sulphate, a substance which oxidizes very rapidly, to the jelly should be avoided; when required for use, the gelatine layer should be sponged over with a fresh solution of ferrous sulphate (D. A. Spencer, 1928).

scraped with a putty knife, and re-melted, together with a suitable proportion of fresh jelly, for use again.

774. Printing on Ferro-prussiate Paper from Ordinary Negatives. The ferro-prussiate papers, as prepared for copying tracings, are, with the exception of the slowest varieties, not usually very suitable for making full-tone prints, and are only sold in quantities which are too large for ordinary photographic use, there being a great risk of such papers deteriorating before a roll is finished. Nevertheless, use may be made of these papers for record purposes, the prints forming a kind of "register" of the negatives.

The sensitizing of papers and cloths (linen and cotton) by the ferro-prussiate process, in small quantities, can be carried out by hand, but commercial papers coated by machine are more uniform and are of higher printing speed.

If required, a ferro-prussiate print may be drawn over with pencil or indelible ink, the image being then removed by immersing it in an approximately 5 per cent solution of oxalic acid, followed by washing in several changes of water. The same solutions can be used for sensitizing fabrics (linen or cotton) by immersion. The working methods are identical: the fabric should be stretched during drying, and, after printing and washing, should be ironed while slightly damp.

Linen and cotton fabrics which have been "mordanted" by the formation of a ferro-prussiate image can be dyed quite easily. For example, a beautiful violet-purple tone is obtained with a bath of boiling alizarine dye. The image should then be washed in hot soap and water, rinsed, lightly starched, and ironed.

OTHER COMMERCIAL IRON-PRINTING PAPERS

775. Cyanotype Paper. Cyanotype paper (H. Pellet, 1878) yields copies consisting of blue lines on a white ground when printed under a tracing. This paper, which is impregnated with a mixture of ferric salts and gum arabic, has a sensitivity comparable with that of the fastest ferro-prussiate papers, and, consequently, can only be handled in a very weak light. As the image is only slightly visible before development (light yellow lines on a white ground), the printing is timed by means of trial strips exposed under a tracing of the same opacity on which a few lines have been drawn in indian ink, these test strips being developed one by one as printing proceeds.

The print is developed without intermediate rinsing as soon as it has been removed from the printing frame, the paper being floated on a 10 per cent solution of potassium ferrocyanide.¹ The time of development should not exceed about 30 seconds, otherwise the lines tend to spread. If placed in the developer, a sheet of unexposed paper would become uniformly blue, whilst a sheet which had been uniformly exposed to the sun for a few moments would remain white. Under-exposure is therefore shown by coloration of the ground, and over-exposure by a lack of depth of the lines. Care should be taken to avoid wetting the back of the paper during development; the four sides of the sheet of paper are turned up so as to form a kind of dish, which is floated on the bath, the hands being gently passed over the back of the paper to ensure uniform wetting at the under surface.

After a short wash, the prints are fixed in a 4 per cent solution (by volume) of sulphuric acid² or a 10 per cent solution of hydrochloric acid. This bath dissolves the gum which has not been rendered insoluble, and at the same time washes away the white ferrous ferrocyanide formed in the lines of the image, and which would gradually turn blue on oxidation. The final washing should be done with a strong jet of water, or, failing this, the print should be brushed under water to dislodge particles of gum arabic not removed in the acid bath.

Cyanotype paper is useless for printing from full-tone negatives.

776. Ferro-gallic Papers. Ferro-gallic paper (A. Poitevin, 1861) gives copies in purplish-black lines on a light ground when printed under a tracing. Its preparation differs very little from that of cyanotype paper, but the coating is slightly less sensitive. Printing is timed with the aid of test strips, developed as printing proceeds.

Development is carried out, without intermediate rinsing, as soon as the paper is taken from the printing frame, by floating it on a bath made up, for example, as follows—

Ordinary alum	. . .	15 g
Gallic acid	. . .	90 g
Water to make	. . .	1000 g

The gallic acid may be replaced by tannic acid

¹ Potassium ferrocyanide, $K_4Fe(CN)_6$, occurs as large lemon-yellow crystals, easily broken up or crushed with very slight pressure. They are slightly efflorescent, very soluble in water (about 25 per cent at 60°F), the solution so formed keeping almost indefinitely.

² Care should be taken in mixing sulphuric acid with water. The acid must always be added to the water and not vice versa.

A very small quantity of oxalic acid may be added to obtain purer whites. Development should last about three minutes. Under-exposure causes the lines of the image to spread, the ground becoming deeply coloured; with over-exposure the lines are broken and faint. The ground is always tinted a light violet colour. An exhausted bath gives only a very weak image. The developed print is washed in several changes of water; a very dilute bath of hydrochloric acid used between two washings will often lighten the ground of an under-exposed print.

The copies should first be dried as much as possible by pressure between blotting paper, otherwise the lines tend to spread while drying.

Ferro-gallic papers have been almost entirely replaced by diazotype papers. The only type of ferro-gallic papers still occasionally used are those which only require washing in plain water. With such papers, the gallic acid necessary for development is applied, with polishing brushes, as a very fine powder on the surface of the sensitive layer as soon as the latter has been dried. The first washing must then be carried out in a fairly small quantity of water so as to avoid excessive dilution of the very small quantity of gallic acid adhering to the paper.

Ferro-gallic papers are not suitable for printing from full-tone negatives.

SILVER-IRON PRINTING PAPERS

777. Sepia Photo-copying Papers. "Sepia" paper (H. Shawcross, 1889), which is prepared by soaking thin translucent paper in a solution containing ferric ammonium citrate, citric acid, and silver nitrate, is widely used for making copies from ink tracings. Such copies, in white lines on a brown ground, may be used as negatives for making prints on ferro-prussiate paper. In this way it is possible to obtain copies in blue lines on a white ground with the latter paper. In this case printing is done by exposing the sensitive surface of the "sepia" paper in contact with the side of the tracing bearing the design, while the blue print is made with the sensitive surface in contact with the image side of the negative.

The keeping properties of "sepia" paper are determined principally by the deterioration of the paper support, the mechanical resistance of which is very quickly reduced, especially at high temperatures.

During the exposure to light, the image

appears gradually, and the printing can thus be judged by inspection. On removal from the printing frame, the paper is placed at once in a 2 per cent solution of hypo, in which it is allowed to remain for about five minutes; it is then washed in several changes of water. Although the image does not appear very opaque, it absorbs nearly the whole of the radiations to which ferro-prussiate paper is sensitive; its effective opacity is thus very much greater than its apparent opacity.

Sepia paper negatives, made from tracings, are occasionally used for process work.

As a rough indication, the approximate *relative times of exposure* which are required to give prints on the various types of commercial papers used for the copying of tracings are given below.

Cyanotype paper	10
Ferro-prussiate paper	10-50
Ferro-prussiate cloth	25
Ferro-gallic paper (water bath)	40-50
Sepia paper	25

778. Kallitype and Imitation Platinum Papers. Soluble ferric oxalate is reduced to the insoluble ferrous oxalate by the action of light. The latter salt is a powerful reducing agent but, by reason of its insolubility, it is unable to reduce silver salts unless a solvent of this salt is added in the form, for example, of a concentrated solution of alkali oxalates or tartrates.

This reaction may be used in three different ways—

1. The paper is sensitized with ferric oxalate; the image is developed with a solution containing both the silver salt and a solvent of the ferrous oxalate.

2. The paper is sensitized with ferric oxalate to which a silver salt has been added. The image is developed with a solvent of ferrous oxalate (Kallitype paper).

3. The paper is sensitized with a mixture of ferric oxalate, a silver salt, and a large excess of alkali oxalates. The image is developed in plain water by immersion or by steaming (imitation platinum paper; E. Boivin, 1891).

We will confine ourselves in this instance to indicating the method of preparation and the use of a Kallitype paper, according to a modification (N. C. Hawks, 1916) of the original working methods of W. W. J. Nicol (1890).

A good quality drawing paper is given a supplementary sizing of starch, arrowroot, or gelatine (the paper being floated on a 1.5 per cent paste or solution); when dry, it is coated

with the following sensitizer by means of a soft brush—

Ferric oxalate	225 g
Neutral potassium oxalate	55 g
Silver nitrate	55 g
Distilled water to make	1000 ml

After drying, it is exposed to daylight until the outlines of the shadows are visible.

According to circumstances, a 2 per cent solution of potassium bichromate is added to the developer given below. This permits of the contrast of the print being regulated as required within wide limits, the contrast being increased as the bath is made richer in bichromate (medium quantity: 6 ml per 100 ml of the developer).

Borax	50 g
Sodium tartrate	60 g
Warm water to make	1000 ml

The sodium tartrate may be replaced by Rochelle salt (sodium-potassium tartrate). The developer prepared in this way gives black tones; warmer tones may be obtained by reducing the quantity of borax; the addition of a few drops of phosphoric acid produces a purple tone.

Development may be carried out in two baths, one containing the average quantity of bichromate, the other containing none (or very little). Development is begun in the first bath and continued in the second if the contrasts seem excessive.

After development, wash for two minutes in plain water, and fix in a very dilute solution of hypo (about 3 per cent), made alkaline by the addition of a few drops of ammonia (being extremely dilute, the fixing bath should be renewed very frequently). Afterwards, wash in five or six changes of water, press between blotting paper, and put to dry. If iron salts are not completely eliminated during washing the image will fade. To guard against this prints should be rinsed, after washing in two baths of 1 per cent hydrochloric acid, and again washed before drying.

The prints obtained in this way may be treated with any of the toning baths which are used for silver print-out papers.

PLATINUM-IRON PRINTING PAPERS

779. Platinum Papers. Pictures consisting of reduced metallic platinum may be obtained by methods similar to those indicated in the two preceding paragraphs by using potassium chloroplatinite instead of silver nitrate. The com-

mercial "platinum" papers were similar to kallitype paper in that they contained the ferric oxalate and the chloroplatinite and required developing in a solution capable of dissolving the ferrous oxalate formed (W. Willis, 1878).

Unfortunately commercial platinum papers are no longer available, but it is possible for the keen experimenter to manufacture satisfactory papers of this type. A suitable method is given in § 780.

Platinum prints, apart from the pigmentary quality of the image, which is not covered by any glossy coating, have the rare quality of being entirely unaffected by all the usual destructive reagents, that is, as long as the paper forming the support is able to resist them. Platinum prints have been recovered intact from a sunken ship which was re-floated after several years. Unfortunately, the extremely high price of platinum considerably restricts the use of this fine printing process. "Palladium" papers, with almost identical properties, have been used but even this metal reaches prohibitive prices.

Platinum papers are extremely susceptible to damp, and were therefore usually supplied in metal tubes which had been hermetically sealed after desiccation.

Platinum papers are only suitable for making prints from negatives of fair but not excessive contrast.

Owing to their high sensitivity,¹ platinum papers should only be handled in a very weak light, both when loading and unloading the printing frame, as well as when examining the progress of printing.

The sensitive surface of the paper is of lemon-yellow colour; the image appears as purplish-grey, inclining to a light orange-brown in the densest parts of the shadows when fully printed. No details should be visible in the high-lights.

Various toning processes have been suggested for platinum prints²; the toned images, however, no longer possess those qualities which distinguish a print on platinum paper, and at the

¹ Failures have been known to occur when platinum papers have been used for making prints from negatives which have been intensified with mercury (light marks appearing to correspond with a local densitization).

² Uranium toning (and similar processes) of platinum prints is not effected by attack of the platinum, as in silver images, the platinum remaining unaltered in the toned image, having merely played the part of a catalyst in the deposition of the coloured ferrocyanide (A. von Hübl, 1893).

same time are not of undoubted permanence. For these reasons the processes will not be described.

780. Sensitizing Papers for Platinum Printing. The preparation of platinum papers having similar characteristics to the commercial papers formerly obtainable is possible, but such papers possess bad keeping qualities, and must therefore be prepared in very small quantities at a time. The accurate weighing-out of small amounts of the materials of the sensitizing bath is a delicate matter.

However, the sensitization with ferric oxalate of a paper which is to be developed with a solution of potassium oxalate containing potassium chloroplatinite does not present any particular difficulty. The method given below is due to W. S. Davenport (1900).

A smooth or rough paper, according to the size of the prints to be made, is chosen. Papers intended for water-colour drawings should preferably be used. Although such papers are already sized, it is a good plan to apply an additional sizing in order to confine the image to the surface of the paper. If this is not done, the image is partially buried in the substance of the paper base itself.

Put 8 g of white gelatine to swell in about 1 litre of water, melt on a water-bath, and add about 2 g of ordinary alum, filtering, if necessary, through closely-woven cloth. Pour the hot liquid into a dish, and float the paper face downwards on the solution after marking the back of the paper with a pencil. If necessary, the bath should be warmed up from time to time, so as to avoid over-sizing the paper, in which case there would be a risk of the image not adhering to it. After a few minutes in contact with the solution, the paper should be allowed to drain and then put to dry away from dust.

The sensitizing solution should be prepared in weak daylight or in artificial light. For this purpose the following should be dissolved—

Ferric oxalate scales	25 g
Oxalic acid	2 g
Lead oxalate ¹	1 g
Hot distilled water to make	100 ml

¹ The lead oxalate, which is necessary to aid the reduction of the platinum salt, should be prepared by mixing equal volumes of a 10 per cent solution of lead acetate and a 4 per cent solution of oxalic acid; a white precipitate of lead oxalate is formed, which should be collected on a filter, washed several times, and then allowed to dry.

The solution is then decanted or filtered, to get rid of small quantities of undissolved lead oxalate if present.

The image will adhere to the paper more easily if a very little potassium chloroplatinite is added to the sensitizer, in very much smaller amount than that required to form a platinum image. For example, about 1 ml of a 10 per cent solution of potassium chloroplatinite can be added to 10 ml of the sensitizing mixture given above. By this method very soft pictures can be obtained from contrasty negatives. The contrasts of a picture can be increased by adding to the same mixture a few drops of a 10 per cent solution of potassium bichromate. When coating rough papers, which tend to absorb a larger quantity of liquid, the sensitizing solution may be slightly diluted.

The sensitizer, contained in a small cup, is spread over the paper with a large brush (this should not have any metal binding) in the same way that a flat wash tint is applied to drawing paper. The paper should be dried fairly quickly; it should be allowed to remain in the atmosphere of the room for about 20 minutes, drying then being finished off by hanging the paper near a stove or heater.

Platinum papers are very susceptible to damp and the unused sheets should be kept in a dried atmosphere, for example in a tin fitted with a double bottom containing a drying material such as silica gel. When printed, the image is not strongly visible, and it is only by experience that one is able to judge what the appearance of the image should be when correctly printed.

The developer is prepared by adding one part of a 10 per cent solution of potassium chloroplatinite to 10 parts of a mixture such as the following—

Neutral potassium oxalate	200 g
Di-sodium phosphate	50 g
Water to make	1000 ml

Some precautions should be taken to ensure uniformity of development, especially if only a very small quantity of liquid is used. A soft, preferably camel-hair, brush, about 1 in. to 1½ in. wide, should be used for the smaller sizes, while a 2 in. brush is essential for the large sizes. It should be moved over the picture with a quick, light movement, dipping it in the developer for each stroke so as to ensure an equal and uniform action of the solution.

As soon as the print is uniformly impregnated, it is left until development is complete.

781. Fixing and Washing. Platinum prints are fixed, *without intermediate rinsing*, in several successive baths of weak hydrochloric acid (15 ml of pure concentrated acid to 1 litre of water), in which the iron salts and the excess of chloroplatinate are removed. The prints should remain about 5 minutes in the first bath, 10 minutes in the second, and 15 minutes in a third. If

the operations have been carried out correctly the third bath should remain colourless. If it does not a further additional bath should be used.

After fixing the prints should be washed for 15 minutes in several changes of water, but they should not be pressed between blotting paper to dry as this sometimes causes stains.

CHAPTER XLV

PIGMENT PROCESSES

GENERAL CONSIDERATIONS

782. Bichromated Colloids. Organic colloids of animal and vegetable origin (e.g. gelatine, albumen, casein, gum arabic, shellac) and also some sythetic materials (e.g. some cellulose or polyvinyl esters) may be rendered light-sensitive by impregnation with a bichromate. Light action on such sensitized materials renders them less soluble in solvents which normally dissolve them easily. For instance, bichromated gelatine which is easily dispersed in warm water before exposure, becomes virtually insoluble in very hot water after exposure. Also, after exposure these materials become less inclined to swell in liquids which normally swell them easily. For instance, bichromated gelatine which readily swells in cold water before exposure, shows practically no swelling in cold water after exposure.

These effects are utilized in many photographic and photo-mechanical printing processes.

The hardening reactions which are brought about by exposure to light also take place slowly in the dark. Thus it is usually desirable to add the bichromate to the colloid only shortly before it is required for use.

783. Chromates and Bichromates. Either potassium or ammonium bichromate is usually used for sensitizing colloids. Sodium bichromate is difficult to purify and should not, therefore, be used.

Potassium Bichromate ($K_2Cr_2O_7$) is in the form of large orange crystals which are unaffected by exposure to air, soluble in water at 50°F to the extent of about 8 per cent and in boiling water over 50 per cent. It is insoluble in alcohol and is precipitated from aqueous solutions if an appreciable proportion of alcohol is added.

Ammonium Bichromate ($(NH_4)_2Cr_2O_7$) is in the form of crystals and is redder in colour than the potassium salt. It is unaffected by exposure to air and is very soluble in water, over 20 per cent at 60°F and about 100 per cent at boiling point. Aqueous solutions up to a concentration of 10 per cent can be mixed with nearly three times their volume of acetone or alcohol without precipitation occurring.

Pyridine Bichromate ($Cr_2O_7H_4C_5H_5N.11H_2O$) in the pure state, is in the form of stable orange-

red crystals and is completely soluble in water. In the impure state it is unstable and is in the form of blackish-brown crystals which have an unpleasant odour and leave an insoluble residue when dissolved in water. It confers greater sensitivity in smaller amounts than do the mineral bichromates. However, the sensitized materials do not keep so well. It has been used principally in the photo-chemical industry.

A simple solution of bichromate in water is quite stable. A solution to which organic substances have been added will gradually turn brown if exposed to the air, and can then produce spontaneous hardening of gelatine.

The addition of ammonia or a caustic alkali to a solution of bichromate changes the colour gradually from orange to lemon yellow, by converting the bichromate into a neutral chromate. Conversely, neutral chromates in solution can be converted to bichromates by the addition of acid. Even weak acids such as acetic acid will do this.

Ammonia is frequently added to solutions of the bichromates used for sensitizing gelatine up to the point of forming the neutral chromate. The ammonium chromate thus formed does not cause the spontaneous hardening of the gelatine which occurs in bichromated gelatine. On exposure to light the ammonium chromate is first decomposed to ammonia and ammonium bichromate, the sensitivity being then hardly less than that of gelatine sensitized with bichromate. The mixture of chromate and unpigmented gelatine is lighter in colour than bichromated gelatine. The image of brown oxide, which is as dark as with bichromated gelatine, is therefore more visible and this has led many workers to assume that the addition of ammonia to bichromate solutions confers greater sensitivity.

784. Physiological Effects of Bichromates. The chromates and bichromates are poisonous but their solutions are of sufficiently distinctive colour to prevent them being mistaken for drinkable liquids. Contact of any skin abrasion with cold solutions of bichromates at the strength normally used in photographic processes can produce a painful sore or even a serious ulceration. Any scratch should be protected by an

application of collodion or a fingerstall. In the event of accidental contact with the solution, copious rinsing should be followed by washing with hydrogen peroxide which decomposes the bichromate.

The first symptoms of bichromate poisoning are generally shown by irritation between the fingers and on the backs of the hands. This is followed by the formation of watery pimples. The skin then becomes dry and peels off in scales. The use of carbolic soap, with a lotion of carbolyzed glycerine and ointment containing mercuric nitrate, generally results in a rapid improvement. Regular scrubbing of the hands with carbolic soap is a safety precaution which should always be taken even by workers who have never been troubled by bichromate poisoning.

785. Spontaneous Hardening on Keeping. The same decomposition of bichromate into neutral chromate and chromium oxide which takes place in aqueous solution, takes place, although to a small extent, in a bichromated colloid layer which is air-dry. Fundamentally this is a similar effect to the tanning of gelatine by chrome-alum or the commercial chrome tanning of hides. The tanning of the colloid, which would be very rapid if it were treated with a solution of chromium oxide, is very slow because the concentration of chromium oxide formed in the layer by the decomposition of bichromate is extremely small. However, anything which tends to upset the equilibrium and cause further production of chromium oxide will accelerate the tanning which would otherwise proceed slowly and progressively with the age of the layer. Acceleration of this spontaneous hardening is caused by storage in humid conditions or at a high temperature.

There are several ways of inhibiting this spontaneous hardening: (a) The addition of neutral chromate which tends to shift the equilibrium so as to inhibit the formation of chromium oxide. (b) Storage of the sensitized material in an atmosphere desiccated by fused calcium chloride. Hydrolysis appears to be impossible in a perfectly dry layer. (c) Storage in a refrigerator. (d) Addition of an oxidizing agent such as potassium ferricyanide which is more easily reducible than bichromate (P. C. Smet-hurst, 1946).

786. Action of Light. In the presence of organic matter the bichromate is thought to be decomposed by light action into neutral chromate, which is subsequently washed out, and

brown chromium chromate $\text{Cr}_2\text{O}_3 \cdot \text{CrO}_3$. During subsequent washing this is split up into chromic acid CrO_3 which is soluble and is washed away, and chromium oxide Cr_2O_3 which combines with the colloid and tans it. The insoluble image probably consists in combination with chromium oxide. The amount of water in a bichromated colloid layer has a great influence on its sensitivity. In liquid form or even in jelly form, bichromated gelatine has a sensitivity so low as to be negligible. A bichromated gelatine layer which has been stored for several days with calcium chloride, although it may still contain 5 per cent of free water is also almost insensitive. Maximum sensitivity is attained at a definite humidity. Temperature variations have little effect on the sensitivity provided they are not accompanied by changes in humidity.

If two identical exposures are made on a bichromated colloid layer and one is washed immediately after exposure while the other is kept for some time before washing, it will be found that the sample which was kept is exactly as it would have been if it had had a longer exposure. This effect is somewhat similar to spontaneous hardening in the dark except that in this case the additional hardening is approximately proportional to the exposure received by the layer at each point. The apparent increase of exposure in a print on bichromated gelatine which has been kept 6 hours before washing is of the order of 15 to 30 per cent.

R. I. Reed and P. W. Dorst (1932) studied the spectral sensitivity of bichromated colloids. They showed that the sensitivity to the equal-energy spectrum was relatively high in the ultra-violet region, fell off rapidly at about $325 \text{ m}\mu$, rose again to a maximum at $355 \text{ m}\mu$ (where the sensitivity is about $\frac{1}{2}$ of that at $210 \text{ m}\mu$), fell off rapidly again at about $400 \text{ m}\mu$ and then more slowly until it became zero at $580 \text{ m}\mu$.

Since ultra-violet radiation of the shorter wavelengths is absorbed by glass, the effective sensitivity in practice is in the wavelength band $355 \text{ m}\mu$ – $400 \text{ m}\mu$. Thus it is necessary to use light sources with a high output in this region and it is desirable to use printing frames with glasses as thin as possible.

Chromates and bichromates absorb ultra-violet, violet, and blue radiation. The maximum absorption of potassium bichromate is at $357.5 \text{ m}\mu$ and of ammonium bichromate is at $367 \text{ m}\mu$ (R. Titeica, 1935). The sensitized layer is in effect, a coloured filter layer which absorbs

radiations to which it is most sensitive. This has the effect of restricting penetration of the useful light and therefore the contrast of the print will be strongly influenced by variations in bichromate concentration. A strong bichromate concentration will result in low contrast since the filtering action will be so pronounced that there will be little light penetration.

The addition to a bichromated colloid layer of a metal salt which precipitates on contact with a chromate but not with a bichromate can confer a threefold increase in sensitivity. The mechanism of this effect was studied by F. J. Tritton (1929). The metal salt does not, itself, contribute to the tanning action but reacts with the neutral chromate which is formed during exposure and thus increases the tanning. The best results have been obtained with cerium and lithium which precipitate with chromates at pH values between 8.0 and 8.5. The pH of the sensitizer must be maintained between these limits.

Sensitometric studies have been made on bichromated layers containing no pigment (J. Bonček, 1935), on silver bromide positive plates sensitized with a bichromate solution, dried and exposed through the back (A. C. Hardy and F. H. Perrin, 1928) and on carbon pigment papers, i.e. papers coated with bichromated gelatine and a pigment such as carbon (A. Schuller, 1913. V. Richter, 1924) with particular attention to those used for photogravure (K. H. Kailich, 1939).

The characteristic curves have the same general shape as those of silver-halide sensitive materials. Maximum speed and contrast are obtained with a bichromate content of about 6 per cent (calculated on the weight of air-dry gelatine).

For a given paper coated with a bichromated gelatine and containing a pigment, transmission densities are proportional to the thickness of gelatine, although the density for a given thickness of gelatine depends on the concentration of pigment in the layer and will vary for different papers. The straight-line portion of the characteristic curve is very long. The slope of the curve increases for a decrease in bichromate concentration and is also dependent on the wavelength of the exposing light. Light which is absorbed less by the bichromated layer gives a steeper slope.

The exposure required is not exactly inversely proportional to the intensity of the exposing

light. If the intensity is halved, a little more than double the exposure is required.

Instead of sensitizing colloids directly with bichromates it is possible to sensitize the layer with various organic substances which can be photo-chemically reduced and whose reduction products will react with a bichromate solution, applied after exposure, to tan the colloid. For instance a gelatine-coated paper sensitized with 2:7-sodium anthraquinone disulphonate will keep indefinitely in the dark. After exposure to light, the paper may be soaked in a 2 per cent solution of bichromate, when the gelatine will be tanned in the same way as it would have been if it had been bichromate-sensitized in the first place (G. Koegel, 1925).

It has been suggested that colloids can be sensitized by condensation products of hardening aldehydes and of diazo compounds. Exposure to light liberates the aldehyde and hardens the colloid. Gelatine can be sensitized with dyes such as Erythrosin or Auramine.

THE CARBON PROCESS

787. Advantages of the Carbon Process. The carbon process is certainly the most beautiful printing process that a photographer can employ when he is not aiming at a personal modification of the negative. It is one of the most flexible from the point of view of choice of colour and contrast. It is also one of the few photographic processes which yield practically permanent images on almost any support at the choice of the photographer. Moreover it is one of the easiest processes to carry out although it is generally believed that it is difficult to master. This seems to be the chief reason why it is not more widely used. Although, unfortunately the carbon process has almost been abandoned by amateur and professional photographers alike, it is an important stage in the photogravure process. The amount of carbon pigment paper used by the photogravure industry to-day is far greater than that which was used by photographers at the height of popularity of the carbon process.

788. Transfer of the Gelatine Layer. The first attempts to obtain photographic prints by using gelatine films sensitized with bichromates and coloured with a pigment were successful only for line images. In the original experiments a layer of gelatine containing finely ground carbon black was sensitized with bichromate and exposed under a negative. After exposure the parts of the layer which had been obscured by

the negative and were therefore still soluble, were washed away in warm water leaving a positive image in hardened gelatine (A. Poitevin, 1855). Attempts to obtain continuous tone images in this way were unsuccessful and this was explained in 1858 by Abbé Laborde.

When a bichromated gelatine layer is exposed to light it is first rendered insoluble near the

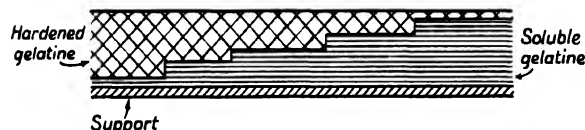


FIG. 45.1. BICHROMATED COLLOID LAYER EXPOSED FROM THE FRONT

surface. As the exposure proceeds the hardening action goes deeper into the layer. However, only in those areas which are exposed behind the lowest densities of the negative will the hardening penetrate deeply. Under the middle tones of the negative, the insoluble gelatine will remain separated from the support by a layer of soluble gelatine (Fig. 45.1). Even if sufficient exposure were given to tan the gelatine right through to the base behind the lowest densities of the negative, the soluble gelatine underneath the less-exposed portions would melt when the layer was treated with warm water and the image would float off the support.

One way of overcoming this difficulty is to expose the gelatine layer through the support. The hardened gelatine image is then formed in contact with the support and the remaining soluble gelatine can be successfully washed away in warm water, leaving the image adhering to the base. This method was used in 1858 by J. C. Burnett who used a paper support for his gelatine layer and in 1861 by Fargier who used a transparent base.

This method has been revived with a variation recently and is known as "wet carbon." This was developed primarily for use in natural-colour photography and was described by F. W. Sharp in 1945. Specially manufactured carbon pigment paper is sensitized by immersion in bichromate solution and squeegeed face downwards on thin clear celluloid which has previously been coated with a thin layer of wax. The exposure behind the negative is made through the celluloid while the gelatine layer is still wet. After exposure the image is developed in warm water on the celluloid. The image can be subsequently transferred to another support.

Since the exposure has to be made to a high-intensity light-source, it is necessary to take precautions against melting the wet gelatine layer by heat from the lamp.

In 1864 J. W. Swan found the first really satisfactory solution to the problem when he devised the method of transferring the gelatine layer to a new support after exposure but before the warm water development. He used paper coated with rubber solution as a temporary support on which to develop the image. This method resulted in a laterally reversed print and it is usual to correct this by re-transferring the developed image to a gelatine-coated paper or other final support (Fig. 45.2).

789. Preparation of Carbon Pigment Paper. Papers for carbon printing in a wide range of colours and of excellent quality are obtainable commercially. It is desirable, however, to describe briefly how they can be prepared by amateurs who have the necessary time at their disposal. Home-made pigment papers can, if desired, have the bichromate incorporated in the gelatine layer and this makes separate sensitization unnecessary.

A fairly porous paper unsized or only slightly

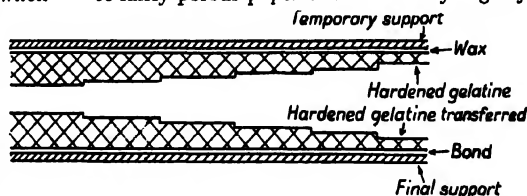


FIG. 45.2. BICHROMATED COLLOID LAYER DEVELOPED ON TEMPORARY SUPPORT AND TRANSFERRED

sized is most suitable as a support. The plain smooth paper sold by wall-paper manufacturers as lining paper for use under patterned papers, is suitable for the purpose.

Moist tube water colours are best for pigmenting the gelatine, but as they are expensive some workers may prefer to use dry powdered colours. Care should be taken in choosing suitable pigments as some react with bichromate and cause spontaneous tanning of the gelatine. Some lamp-blacks are greasy and are not easily wetted by aqueous solutions. These should be avoided. The powder colours should be ground in a mortar with an equal weight of glucose syrup.

The soft type of gelatine used for collotype printing is very suitable for this purpose but

the addition of a small proportion of hard gelatine will increase the sensitivity of the paper if required. The gelatine should be soaked in cold water until thoroughly swollen and then dispersed in the water which it has absorbed, by warming over a water bath. The temperature should not exceed 160°F. Sugar should be added to keep the final dry gelatine layer flaccid. Commercial pigment papers usually contain a small proportion of soap in addition. The colour is now thoroughly mixed into the gelatine and the mixture strained through fine fabric ready for coating on the paper.

The following formula, which is given as an example, is suitable for making prints or transparencies in black. The quantity given is sufficient to coat 10 sq ft of paper for making prints or 6 sq ft of paper for making transparencies. For making relatively thick reliefs for special purposes as much as 6 oz of gelatine may be spread on 10 sq ft of paper in which case the pigment content should be reduced but the quantity per square foot should not be below that used for papers with normal thin gelatine coatings.

Gelatine	50 to 80 g
Loaf sugar	10 to 20 g
Salicylic acid	0.25 g
Vegetable black	10 g
Indigo	0.5 g
Carmine	1 g
Glucose syrup	10 ml
Water	250 ml

There are several methods of coating the paper but the following is a good one (E. Felloes, 1920).

A printing frame is taken (an old one will do perfectly well) and some sheets of glass a little smaller than the rebates so as to leave a little play. The paper is cut into sheets about 1½ in. bigger each way than the frame. A sheet of paper and a sheet of glass are immersed in water at about 120°F. The paper is laid on the glass, covered with a sheet of grease-proof paper and the paper is firmly squeezed on to the glass, removing as much water as possible. The edges of the paper are folded behind the glass which is then placed in the printing frame so that the paper is seen from the front of the frame. The back of the frame is closed and it is turned face upwards. While the paper and glass are still warm, the gelatine mixture is poured into the "dish" formed by the edges of the frame. The frame is left in a level position until the gelatine is set and then the gelatine is separated from the wood by means of a sharp

knife. The glass is removed together with the coated paper which is left to dry thoroughly. When it is dry the paper is removed from the glass and kept flat until required.

When ready-sensitized pigment paper is required, before the colour is added to the coating mixture, 60 to 120 gr (4 to 8 g) of potassium bichromate and 15 gr (1 g) of sodium citrate should be mixed with the gelatine. Sufficient ammonia solution should then be added to change the colour from orange to lemon yellow.

SENSITIZING AND EXPOSING CARBON PIGMENT PAPER

790. Sensitizing. Carbon pigment paper which has been stored for a long time in a dry atmosphere is likely to become brittle. This leads to a risk that the gelatine layer will crack or split during handling before sensitizing. In view of this it is advisable to take the precaution of leaving the paper in a humid atmosphere for a few hours before use. This is particularly advisable when the paper is in rolls, and the wrappings should be removed to allow full access of the air. On the other hand, long storage in a damp atmosphere should be avoided as there is a danger of formation of mildew and even of parts in contact adhering in patches. Sufficient paper for a few days should be cut into sheets and kept flat between sheets of glass. Care should be taken not to touch the gelatine surface as fingermarks are likely to cause a blemish in the final print. Finger prints and scratches from finger nails may both be avoided by wearing cotton gloves.

The pigment paper can be sensitized by immersion in a solution of bichromate or by brushing the solution on the surface. The second method is usually used with spirit sensitizers in order to economize in solution.

The paper may be sensitized in daylight but not in full sunlight.

Plain metal dishes should never be used for the sensitizing bath as they are liable partially to reduce the bichromate. Bichromate solutions which have been used for sensitizing are liable to change and if used again may cause spontaneous hardening. This is more likely to happen if the used solution is exposed to bright light. Sensitizing solutions should, therefore, be stored in the dark and should not be kept for more than a few days after their first use.

791. Gelatine is more soluble in a bichromate solution than in plain water and it also swells to

a greater extent. In hot weather, therefore, it is desirable to cool the sensitizing bath to 55°F or, at most, 60°F. This is usually done by standing the sensitizing dish in a larger one containing crushed ice in water. If this is not convenient, sensitizing should be done with a bichromate solution in a mixture of industrial spirit and water applied with a brush. Alternatively, a proportion of industrial spirit may be added to the normal sensitizing bath. If these precautions are omitted there is a serious risk of the gelatine being reticulated.

In damp weather, if no means is available for accelerating drying of the tissue, it is desirable to add a little phenol or salicylic acid dissolved in industrial spirit to the sensitizing bath. This eliminates the danger of bacterial growth in the gelatine during prolonged drying.

The concentration of the bichromate in the sensitizing bath has a considerable influence on the sensitivity of the pigment paper and also on the contrast of the resulting prints. A concentrated solution will give greater sensitivity but comparatively weak prints even from vigorous negatives. Papers with strong colours tend to give contrasty prints and should therefore be sensitized in stronger baths than would be used with papers of lighter colour.

In addition to the concentration of the sensitizing bath, its temperature and its pH affect the speed and contrast of the paper. This is because temperature and pH affect the degree of swelling of the gelatine and thus control the volume of solution absorbed by the layer. Raising the pH of the sensitizing bath increases the contrast of the image by decreasing the density of the least exposed areas without greatly affecting the highest densities. A slightly acid bath produces a paper which is faster than one sensitized in an alkaline bath but more brown chromium dioxide is formed. This strongly absorbs the light and prevents the speed increase from showing itself in the most exposed areas (H. M. Cartwright and H. Murrell, 1933).

The effect of the pH of the sensitizing bath on the relative sensitivity, contrast, and keeping properties of the pigment paper used in the photogravure process was studied by H. M. Cartwright (1944). The pigment paper was sensitized in a 2.5 per cent solution of ammonium bichromate at various pH values and was exposed, after keeping for various times, behind a sensitometric wedge to an enclosed arc. The results are tabulated below. The colour of the bath is not a sufficiently accurate indication of

its pH and colour indicators are useless owing to the strong colour of the solution itself. For this reason it is necessary to use a pH meter for the measurements. It will be seen that optimum results are obtained with a sensitizing bath at a pH of 6.0.

pH	Colour	After 24 hours		Speed after		
		Speed	Gamma	2 days	4 days	6 days
3.0	Orange red	Insoluble	—	—	—	—
3.9	Orange	1.3	0.38	2.5	Insoluble	—
4.3	Orange	1.0	0.4	2.0	2.5	Insoluble
6.0	Pale orange	1.0	0.4	1.5	2.0	2.5
7.0	Orange yellow	0.75	0.42	1.3	2.0	2.5
9.0	Warm yellow	0.5	0.44	0.75	1.5	2.0
11.0	Yellow	0.3	0.48	0.5	1.0	1.5

For printing by daylight the bichromate sensitizing solution may be at a concentration of between 1 per cent for weak negatives to 6 per cent for printing from very contrasty negatives. For normal negatives a suitable concentration would be 3-4 per cent. To enable the sensitized paper to be kept for a few days without special precautions and without sacrificing any speed, neutral chromate should be added to the sensitizing bath. A suitable amount is $\frac{1}{2}$ of the weight of bichromate.

792. For sensitizing in a dish, the solution should occupy a depth of from $\frac{1}{4}$ in. to 1 in., according to the number of sheets to be sensitized at once. Not more than five should be immersed at one time.

The paper to be sensitized should be immersed face downwards. The sheet should be taken by two opposite corners and slid into the solution. As soon as the sheet has become slightly limp it should be turned face upwards, and any adhering air-bells should be broken either with a brush or a plug of cotton wool. It should be quickly turned face downwards again and any air-bells on the back of the paper similarly removed.

The sheet of pigment paper must not be withdrawn from the sensitizing bath until it has become thoroughly limp and perfectly flat. This should require from 2 to 3 minutes. If the time of immersion is too short the paper will be only slightly sensitive, while if it is too long the gelatine will swell excessively and the drying time will be prolonged. In commercial practice it is usual to standardize the immersion time. Sensitizing baths to which have been added

20 per cent of their volume of industrial spirit do not soften the gelatine. The time of immersion ought then to be about 4 minutes to allow the paper to become flat.

To withdraw the paper from the bath, the back of the sheet should be drawn over the edge of the dish so as to remove as much of the sensitizing solution as possible. It is desirable to remove most of the liquid from the surface of the gelatine. To do this, the paper should be placed face downwards on a perfectly clean sheet of glass, and the liquid rapidly expelled by strokes of a squeegee, using moderate pressure.

When it is desired to reproduce images of extreme delicacy, particularly when the carbon print is intended to be used as a resist for etching in certain photo-mechanical processes, the sensitized paper is kept on the glass until dry.

793. Sensitizing by brushing the solution on the tissue may be recommended in case of urgency, or if there is reason to fear veiling by spontaneous hardening due to drying at high temperatures. A solution of ammonium bichromate is prepared of three times the strength required. This should be neutralized by the addition of ammonia if the sensitive paper is to be kept. Twice its volume of industrial (denatured) spirit, should then be added. This mixture may be prepared long enough in advance to obtain a clear solution by decantation. It must be kept in the dark, or, at least, protected from daylight.

The sheet of paper to be sensitized is laid face uppermost on a sheet of glass or card to which it is attached at the corners by wooden clips. The solution is applied by means of a brush or a plug of cotton-wool; the strokes of the brush must be made to cross in each direction, so as to avoid any irregularity.

794. **Drying the Sensitized Tissue.** The drying of sensitized carbon pigment paper should be carried out in a room—or in a box or cupboard—where daylight cannot enter, but where fresh, cool air can be constantly renewed. In addition, if tissue is dried with its face exposed to the air, precautions must be adopted to prevent dust being deposited on the gelatine.

Even in unfavourable conditions, pigment paper sensitized by brushing with a strong alcoholic solution may be thoroughly dried in about half an hour. Paper sensitized by immersion in a plain aqueous solution may require a long time, especially if it has not been squeegeed

to remove excess solution. It is desirable in that case to arrange that a current of air should circulate through the drying cupboard to ensure drying in 4 hours at the most. If drying takes longer than this, veiling will probably result from spontaneous hardening.

In some commercial establishments, where the pigment paper is kept on the glass to which it has been squeegeed until it is dry, drying cupboards are used in which the glasses are arranged horizontally on brackets or shelves, and are traversed by a current of air. The air is provided by a centrifugal fan and is cooled by circulating round a metal container, filled with ice or a freezing mixture, on the sides of which condenses the greater part of any moisture which it may contain. If the glasses are arranged vertically in the drying cupboard, the current of air should be admitted only after they have drained for about 20 minutes. In any case the current of air should reach its full speed only after progressive stages with fairly wide intervals in order to avoid partial detachment of the paper from the glasses.

A most effective method of drying for large-scale production, is to squeegee the sheets of pigment paper to plate glasses and then lay felt blankets impregnated with calcium chloride on the backs of the sheets. The time of contact with the blanket is standardized and a definite degree of drying is thus automatically achieved. After use, the blankets are dried in an oven for re-use. These blankets are in regular use in photogravure plants and are obtainable commercially.

A common practice is to support small sheets on lines by means of wooden clips. Sheets in large sizes are placed over a semi-cylindrical grid, about 8 to 12 in. in diameter, mounted on legs or suspended by cords.

The drying cupboard ought to be fairly cool at first, but the temperature may be raised slightly towards the end of the drying. It is necessary to avoid the use of either paraffin or gas stoves for warming the air. The combustion products would partially harden the moist bichromated gelatine.

Drying is completed when the gelatine film has become *almost* brittle.

795. **Storing the Sensitized Pigment Paper.** In dry weather, when not too warm, carbon pigment paper sensitized in a bath of moderate strength neutralized with ammonia, or with neutral chromate added, can be kept without any special precautions for four or five days.

This time is considerably shortened if the paper has been sensitized in a concentrated solution without any precaution for neutralizing the chromic acid. Spontaneous hardening occurs more quickly if drying has been very slow or if the tissue is kept in a damp, warm atmosphere. This can be retarded and the time of keeping in good condition extended to about ten days if the sensitizing bath contains about 1 per cent of neutral sodium citrate or potassium citrate (§ 747).

Sensitized pigment paper may be kept almost indefinitely in a perfectly dry atmosphere. For example, it may be kept in a metal tube containing drying compounds and sealed with adhesive tape or a rubber band. However, as the gelatine is rendered very brittle and almost insensitive, the sheets should be kept for several hours in a moist atmosphere before being unrolled and used. Sensitized carbon tissue has been kept for three months without change at the temperature of 27°F (O. Watter, 1935).

Although good keeping qualities can be ensured only in a dry atmosphere, sheets of carbon pigment paper may be kept for a time after sensitizing, if they are put in a printing frame, under pressure. They should be perfectly dry and covered with a sheet of rubber before the back of the frame is closed.

796. Preparation of the Negatives. For carbon printing vigorous negatives are desirable, especially for first attempts. Negatives with a density range of about 1.4 are suitable.

Depending on whether the single or double transfer is adopted, negatives must be either reversed or normal. Negatives may be reversed by stripping the film, or they may be made reversed in the first instance by fitting a reversing prism or mirror to the lens. Film negatives can be printed from the back by being reversed in the printing frame, thus allowing single transfer, but it is then necessary to employ a compact light source of small size for printing. The light must also be at some distance from the frame and kept still during the printing in order to get a sharp image, since the negative image is slightly out of contact.

A margin (*safe-edge*) at least $\frac{1}{8}$ in. wide must be protected against the action of the light all round the edges of the pigment paper by means of a mask suitably attached to the negative. Without this precaution it is impossible to ensure adhesion of the pigmented gelatine to the support to which it is transferred for development, whether it be the final support for single transfer

or the temporary support for double transfer. The carbon pigment paper must be cut to such a size that the margins are completely covered by the safe-edge. The paper should be cut with clean edges; there is a risk of defective adhesion to the support during development if the tissue is torn or cut with a paper-knife. The size to which the pigment paper is cut, including the safe-edge, must not exceed the dimensions of the support on which it is to be mounted for development.

Although the safe-edge mask may, if necessary, be applied to the glass side of the negative, it is preferable, as a rule, that it should be on the emulsion side. If on the glass, it must be sufficiently wide to protect the bichromated gelatine beyond the range of the semi-shadow of the light penetrating under the safe-edge. When on the emulsion side the mask may be formed of strips of black paper, or by a margin of black varnish or opaque water-colour. The outlines may be drawn with a draughtsman's ruling pen with large rounded blades, the varnish being applied with a brush beyond these outlines.

797. Exposure to Light. The various manipulations in carbon printing may be carried out in very subdued daylight, by daylight coming through yellow windows, or by unscreened artificial light.

Only a faint image is produced by exposure of the pigmented film to light; the exposure must therefore be determined by means of an actinometer or light integrator. The exposure may also be determined by the fact that, all other conditions being equal, the time necessary for obtaining a print on black carbon tissue will be approximately equal to the time of printing on gelatine-chloride print-out paper. This latter should only be carried up to the point at which the print appears correct since there is no need to fix the print and so no need to allow for any loss of density which this causes.

The sensitivity of carbon pigment paper depends on a number of factors. They are: the colour of the pigment and its proportion in relation to the gelatine; the strength of the solution of bichromate used for sensitizing; the moisture content of the gelatine and also the temperature during exposure. While it is not possible to lay down exact rules, it may be said that, as a rule, the exposure should be longer if the gelatine is very soluble. The spontaneous insolubility of the gelatine by long keeping produces an *apparent* increase in sensitivity. The exposure to light must also be longer

if the proportion of pigment is high, if the sensitizing has been carried out in a very dilute solution, or if the temperature is very low. The time of printing is generally shorter with blue or violet pigment paper than with black; it should, on the other hand, be longer with brown or red pigment paper, and up to three times as long for red-chalk. The printing time should be shortened if the development is to be deferred because the tanning of the image increases, even in darkness. It should be noted, however, that this "continuing action" does not give consistent results.

798. Printing by daylight is preferably done in the shade or in diffused light. When the printing frames are exposed out of doors in damp weather the pigment paper should be protected against access of moisture by being covered with a sheet of rubber. In the absence of this precaution the felt pads which are used to ensure uniform pressure should be thoroughly dried so as to avoid unequal dampness and consequent irregularity in the prints.

It may be said that, as a general rule, printing on carbon pigment paper by artificial light gives prints of lower contrast, all other conditions remaining equal. This reduction in contrast is especially marked when arc lamps on a high voltage are employed, as their light is very rich in ultra-violet rays. For example, the same degree of contrast can be obtained on tissue sensitized in a 5 per cent solution and printed by daylight, and on tissue sensitized in a 1.5 per cent solution and printed by an enclosed arc at 220 volts, 12 amperes.

When arc lamps are used close to the printing frame it is desirable to keep the frame cool by means of a fan. Heating tends to produce overall hardening of the gelatine and give veiled prints. Mercury vapour lamps give very satisfactory results in carbon printing if the concentration of the sensitizing bath is suitably adjusted. With these lamps the danger of heating the frames is avoided.

799. When taking the first print from an uncalibrated negative, it is desirable to compare it with other negatives from which good results have been obtained under known conditions. By making this comparison it is easy to judge the working conditions which will yield good results with the negative in use. When a satisfactory print has been made from the negative a note should be made of the colour of the pigment paper, the strength of the sensitizing bath, and the exposure. Notes of this

sort can be built up into a very valuable record which will assist greatly in future operations. When prints are made by exposure to arc light or discharge lamps operating on mains of reasonably constant voltage, it will be sufficient to record the distance from the lamp and the exposure time. Where exposures are made to daylight, however, it is highly desirable to use an actinometer to estimate their length. The number of actinometer tints required by each negative should then be recorded.

DEVELOPMENT OF PIGMENT PAPER BY SINGLE TRANSFER

800. **Choice of Support.** According to the purpose for which they are intended, carbon prints made for viewing by reflected light may be transferred and developed on paper, on opal glass, on metal, and generally on any support which can resist the action of warm water.

Mat opal glass needs no preparation beyond a thorough cleaning with soap and a brush to remove all traces of grease.

Glass, porcelain, or metal should preferably be thinly coated with bichromated gelatine. After drying, this should receive a long exposure to daylight to render it insoluble. A 3 per cent solution of gelatine to which is added, at the time of using, 0.1 per cent of potassium bichromate, may be used for this substratum. The warm solution should be flowed on ordinary or plate-glass in the manner already described for varnishing negatives (§ 577). The excess is drained off, and the coated plates are dried free from dust. After an exposure of about two hours to daylight, the gelatine-coated supports are ready for use.

Instead of gelatine, bichromated albumen or casein may be used. It is possible to dispense with the substratum altogether if it is quite certain that the surface on which the image is to be transferred is absolutely clean. In the photogravure process, for instance, the pigment paper is transferred directly to perfectly clean copper.

Substances like ivory, which are liable to be permanently stained by the bichromate, should be prepared with a solution of gelatine hardened with alum. To a 5 per cent solution of gelatine is added 0.5 per cent of common alum; this coating becomes insoluble automatically during drying. As an additional precaution the excess bichromate should be washed from the pigment paper with several changes of cold water. The washed print should then be dried before transferring.

Various papers sized with gelatine, or even some heavily baryta-coated papers for collotype printing, etc., can be used as supports for the carbon print by hardening the gelatine with which they are sized or coated. Such papers should be immersed in a 5 per cent solution of chrome-alum for 2 to 3 minutes, and then put aside to dry.

It is generally desirable to use the papers specially prepared for single transfer by the manufacturers of materials for carbon printing, or else to gelatine-coat papers of more varied character, smooth, glossy, grained, tinted, or even with metallic surfaces.

For the preparation of single-transfer papers, the paper chosen is floated on a warm solution of gelatine to which alum has been added. Or, alternatively, after having very slightly moistened the paper with warm water, the gelatine may be applied by means of a large brush. A warm solution of photographic gelatine, about 5 per cent should be used and to this should be added 1 per cent of chrome-alum just before use. This yields a glossy transfer paper; the thicker the coating, the higher the gloss. To obtain a mat coating it is necessary to emulsify in the gelatine-alum solution raw starch previously mixed in water to produce a kind of "milk."

801. Transfer. Single-transfer papers should be cut a little larger than the carbon pigment paper which is to be transferred to them. They are immersed in cold water for 5 to 10 minutes in the case of thin papers, or for 2 to 3 hours for thick and rough papers. With the latter it is frequently advantageous to place the paper in warm water a short time before transferring the print, replacing it in cold water before the exposed pigment paper is applied to it.

Gelatine-coated rigid supports should be soaked in cold water for 5 to 10 minutes.

The best temperature of the water for transferring is 60°F; if air-bells have been formed by the flow of water into the tank, the carbon print should not be immersed in the water until they have dispersed.

Some minutes before the end of the soaking time, the carbon print to be transferred should be placed in the same dish, face downwards. It should be turned over for sufficient time to remove any air-bells that may adhere to the surface, and turned face downwards again. Since the paper absorbs moisture more quickly than the gelatine, the print curls, the gelatine face becoming concave. After a few moments, as the gelatine continues to absorb water, the

print straightens out, and by prolonging the soaking, the gelatine face would become convex. The exact moment when the carbon print becomes flat is the point at which it should be applied, *under the water*, to the prepared surface of the support. The print and transfer paper are withdrawn together, quickly; they are placed on a sheet of thick glass or marble on a table, print uppermost, covered with a sheet of rubber, and the intervening liquid expelled by moderate pressure with the squeegee, the strokes being made from the centre towards the edges. In the case of thick or rough papers it is desirable to finish the squeegeeing into contact by removing the rubber sheet and working the squeegee directly on the back of the paper.

After squeegeeing into contact, the carbon print on its support should be placed between blotting boards for about 15 to 20 minutes in the case of thin transfer papers, or 30 minutes when thick or rough papers are used. During this time they should be kept between thick pieces of glass, loaded with weights. There is, however, no objection to keeping the prints between the blotting boards in this manner for a longer time, provided that they do not become too dry. A carbon print which has been soaking too long before being applied to its support will not adhere. A print insufficiently soaked will only adhere in parts, the suction inducing air to penetrate between the film of gelatine and its new support.

The successive wettings and dryings of the papers, the carbon pigment paper as well as the single-transfer paper, produce alternately expansions and contractions of the image, at right angles to the fibres of each of the papers. In order to compensate for these deformations, it is well to arrange that the various papers used expand in the same direction. Machine-made papers always expand more across the sheet or roll, than in the direction of their length. Hand-made papers expand equally in each direction.

To avoid the expansion and contraction of the print transferred to a rigid support the method known in photogravure work as "dry laying" may be utilized, in which the paper is wetted on its gelatine surface only, and only at the instant of its contact with the support. The support is placed on a slightly sloping table and the carbon paper is laid on it face downwards. A rubber roller is passed over the paper until the lower edge is reached. There, by means of adhesive tape, a strip of the paper

about $\frac{1}{2}$ in. wide along the edge is fixed to the support. The paper is then rolled up, with the pigment layer outwards, until it touches the roller. It is held against the roller which is then slowly moved over the support which is sprayed with a jet of water. The paper unrolls and, at one and the same time, is wetted and pressed into contact with the support (C. Rauch, 1936).

802. Development. The carbon print loses its sensitivity to light as soon as it is wetted for transferring. Consequently, development can be carried out in full daylight if desired; this is desirable in order that the operation may be thoroughly under control.

The finest details in the light tones are very much better preserved when development is carried out at a low temperature.

The transfer papers with the carbon prints adhering to them are immersed one by one in water at about 95°F, the carbon print uppermost. The print is easily identified, as it is smaller than the transfer paper. The water should fill the developing tank to a depth of $1\frac{1}{2}$ in. to 2 in. A large number of prints should not be developed at the same time; there is a serious risk of injury through one print rubbing against another.

Prints on rigid supports can be immersed in the warm water with the print downwards if small blocks of lead are arranged in the tank so that the supports can rest on them without their coming into contact with the print itself. The original paper support will leave the print automatically, and development will proceed without attention. It can be well advanced before the support is turned face upwards for finishing development by pouring water over the print. Development of prints on rigid supports may also be carried out in grooved vertical tanks, or in separate frames used in vertical tanks.

After a few moments, a little of the coloured gelatine from the margin protected by the safe-edge begins to ooze out from the junction of the carbon print and its support. The temperature of the water may now be gradually raised to about 105°F, and then the paper which formed the original support of the print should be gently lifted and drawn away from the support to which the image has been transferred. The original paper can be thrown away. If the paper will not come away easily, wait for about a minute longer, and then, if the paper still offers resistance, raise the temperature of the water to about 112°F by pouring very

hot water, a little at a time, into a corner of the tank, sufficiently far from the prints to avoid injury, mixing it rapidly with the water already in the tank.

When the backing paper is first removed from the print, the image is scarcely visible; it is covered by the greater part of the excess of pigmented gelatine. The print should be turned face downwards to facilitate dissolving away the excess of gelatine, and turned face upwards from time to time to allow the progress of development to be seen.

For development, the print is placed face upwards on a sheet of glass or zinc, somewhat larger than the print. This should be laid on one of the sides of the sink and the bottom of the developing dish, and then warm water should be poured from a jug on to the upper part of the glass or zinc plate, above the print, in such a manner that the water flows evenly over the print and washes away the last of the soluble coloured gelatine.

Development is complete when there are no longer any coloured drainings either on the light tones of the prints or on the lower margin of the print when it is held vertically. The strength of the image increases slightly in drying; the print should, consequently, be a little less vigorous than desired when finished.

The development of a correctly-exposed print requires from two to ten minutes.

If a print is too light it is a sign of either insufficient exposure or the use of water at too high a temperature during development. If other prints have been taken under identical conditions, development should be tried at a lower temperature.

If a print is too dark it indicates either printing for too long a time, or that the pigment paper is veiled, or that the water used for developing was too cool. Development should be continued in hotter water, raising the temperature gradually, but without exceeding 140°F. Beyond this temperature blisters are sure to appear as well as a general reticulation of the gelatine.

Attempts may be made to rectify considerable over-exposure of the print by adding to the water small quantities of ammonia or of an alkaline carbonate. Very small traces of sodium hypochlorite may also be added. Further, the print may be placed for a few moments in a dilute solution of ammonium persulphate. A 2 per cent solution, acidified with a little sulphuric acid, should be used.

It is also practicable, within limits, to lighten the print locally and brighten up the highlights, especially the margins, by lightly rubbing with a tuft of cotton-wool or a soft brush, or by local applications of warm water.

When development is completed, the print should be rinsed in cold water. Then it should be placed in a 5 per cent solution of common alum until the last traces of bichromate have disappeared. The bichromate is removed by alum far more readily than by plain water. If blisters appear in this bath it may be omitted; the residue of the bichromate can be removed by washing in water to which a very small quantity of sodium bisulphite has been added. The work is completed by washing for a few minutes in running water, or several changes of water. The prints should be dried naturally by being hung up on lines, care being taken to avoid touching the image, which is very tender until it is dry.

803. Transparencies and Positives. In addition to the advantage of producing permanent transparencies in any predetermined colour, the carbon process has a long scale of gradation, and, almost throughout the entire length of this scale, a remarkable fidelity of rendering. The characteristic curve (§ 202) is practically a straight line, of which the gradient is always below unity except when the sensitizing bath is reduced in strength to 0.5 per cent of bichromate (A. Schuller, 1913). The contrasts are slightly increased when the sensitizing bath has been neutralized by the addition of ammonia.

This property, in which the carbon process is unique, renders it specially valuable for making positives. It used to be a rule with photographic publishers to keep a carbon transparency of every negative of value. From this transparency it was possible, in case of any accident happening to the original, to make a new negative by the same carbon process.

Carbon pigment papers specially prepared for transparencies are generally richer in pigment, and the colour is more finely ground. Excellent transparencies may be obtained, however, by using the ordinary papers.

To ensure penetration of the light to the greatest depth, it is desirable to reduce the strength of the sensitizing bath to about 1 or $1\frac{1}{2}$ per cent of bichromate, and to add ammonia until the yellow colour is reached.

Glass for transparencies should be selected carefully, free from defects, and as thin as possible, if the transparencies are intended for projection.

When it is desired to intensify the transparencies or to modify their colour, the substratum must be impermeable to water. For example, a solution of rubber in benzene may be used.

The manipulations are the same as those already described in the preceding paragraphs. The control of the development of the image will be facilitated if the transparency is held over a uniformly illuminated white surface.

804. Intensification and Toning of Images on a Waterproof Support. Carbon prints or transparencies transferred to plain opal or to glass prepared with a rubber solution can be strengthened by precipitating an insoluble salt in the image. The simplest method is to immerse the print in a neutral solution of potassium permanganate, which deposits brown manganese dioxide in the gelatine. The stronger the solution of permanganate, or the longer it is allowed to act, the heavier will be the deposit. After the strengthening, a brief rinsing is all that is necessary. Should the intensification be too great, the image can be restored to its original condition by immersion in a very dilute solution of sodium bisulphite.

Black lead sulphide or Prussian Blue, etc., can also be formed in the image by immersing it in a very dilute solution of lead nitrate or potassium ferrocyanide, and then, after a slight rinsing, in a dilute solution of sodium sulphide or ferric chloride, followed by a very thorough washing.

The film may also be stained uniformly by one of the acid dyes previously described for the staining of prints produced by the silver processes (§ 754).

Intensification by means of permanganate can be carried out with prints made by double transfer while they are on the temporary support.

• DEVELOPMENT OF PIGMENT PAPER BY DOUBLE TRANSFER

805. Preparation of the Temporary Support. A carbon print can be transferred, for development, to a large variety of temporary supports, from which it can be transferred, when finished, to its final support. The surface texture of the temporary support very largely determines the surface of the final print.

The following are some of the materials which may be used as temporary supports: opal or plain glass, zinc, aluminium, and enamelled iron, all of which may be polished or mat; and also

celluloid, sheet rubber (hospital sheeting), and varnished paper.

Zinc oxidizes very readily if it is allowed to dry naturally. Pigmented papers with either a white or very light coloured film should be preferably transferred to sheets of ebonite so that the strength of the image can be more easily judged. There is no need to describe methods of preparing temporary paper supports as they are readily obtainable commercially.

Rigid temporary supports can be used only when the final transfer of the image is to be made on a flexible support. The use of a flexible temporary support is also necessary when the image is to be finally transferred to a thick rough paper.

The temporary support, whatever it may be, must be coated with a film that will ensure adhesion of the pigmented gelatine during development. However, this adhesion must be less than that of the image to the film of gelatine with which the final support is coated. These conditions are fulfilled by employing a mixture of wax and colophony, made by mixing the following solutions, which should be prepared without heating.

A	Turpentine	250 ml
	Colophony (rosin)	35 g
B	Benzene (crystallizable)	750 ml
	Yellow beeswax	20 g

The solution thus obtained should be kept in a well-corked bottle. A small quantity for regular use may be kept in a dropping bottle.

Plain or opal glass should be cleaned with a hot strong solution of washing soda, rinsed thoroughly in water, dried at once, and polished with a fine fabric moistened with methylated spirit.

Zinc or aluminium should be cleaned thoroughly with a paste of whitening and water, then placed for a few minutes in a 2 per cent solution of hydrochloric acid and rinsed in plain water. They should then be dried rapidly, either near a fire or in a fast current of air.

Celluloid or rubber sheeting should be cleaned with water containing a small proportion of ammonia, then rinsed in plain water and dried with a thoroughly clean, fine fabric.

A few drops of the waxing solution should be poured on to the temporary support selected, and spread uniformly with a tuft of flannel.

A second tuft of flannel should be used to rub with a circular motion, the circles crossing and re-crossing as in polishing. It should be left for about an hour to allow the solvents to evaporate completely. When any support (other than the papers specially prepared) is used for the first time, it is desirable to wax it several times. This ensures that the mixture of wax and resin covers the entire surface, including the depth of the grain.

After use, the temporary supports should be stored in a dust-free place. They can be used many times in succession without any other preparation than the application of a very thin coating of the waxing solution each time that they are used.

806. Transfer on Temporary Supports. Paper temporary supports must be softened by being immersed in cold water for 10 minutes before the carbon print is squeezed into contact. This time must be increased to about 30 minutes if the back of the paper has been made waterproof by either wax or varnish.

Supports which are completely waterproof need only be immersed in water at the moment of bringing the carbon print into contact with them.

The transfer is effected under conditions identical with those already described for applying prints to their support in the single transfer process (§ 806).

807. Development. Owing to the presence of the film of wax on the temporary support, development of over-exposed prints cannot be carried out at such a high temperature as is possible with a single transfer. The reason for the high proportion of resin in the waxing solution is to raise the melting point of the wax layer sufficiently to make the developing process fairly safe. This limitation of the temperature does not apply when a paper coated with a thin film of unvulcanized rubber is used as the temporary support. When the final transfer is made, however, it is necessary to moisten the back of the temporary support with benzene in order that the print may be separated from it. In addition, the image itself must be cleaned with benzene in order to remove the fragments of rubber which adhere to it.

Apart from this, the development of prints on a temporary support is carried out in exactly the same manner as previously described (§ 802) for the development of prints by single transfer.

In the event of separation of the gelatine

film from its support during development, it should be placed immediately in an alum bath. After a few minutes the print may be quickly rinsed and put aside to dry. The development may be continued, if necessary, after drying.

Washing and the dipping in the alum bath may be slightly shorter than in the single transfer method since the bichromate is unable to penetrate the temporary support.

Except when prints are very urgently required, it is desirable that they should be allowed to dry on the temporary support, after the alum bath and washing, before being transferred. The gelatine will then be less likely to be torn or spread under the pressure of the squeegee when being transferred to the final support. Moreover, the relief of the image will be considerably less and contact between the half-tones and the gelatine of the final support will be more easily ensured. Retouching and spotting can also be done before the final transfer, and will then be practically invisible.

Drying should take place naturally.

808. Preparation of the Final Support. Double-transfer papers of various kinds, thicknesses, and textures are obtainable commercially. They are coated with a thin film of gelatine and meet practically all usual requirements.

All papers of good quality, provided that they do not change by exposure to light or air, can be used as final supports. They must be coated on one face with a solution of gelatine to which a very small proportion of alum, and a very small quantity of glycerine, have been added. The object of the glycerine is to keep the gelatine-coated paper flexible after drying; it is almost completely removed in the soaking of the support preceding the final transfer. Instead of coating paper with gelatine in advance to form the final support, it may be soaked in water until thoroughly soft, and then, at the time of applying it to the temporary support, immersed in hot water and then floated for a few moments on a warm solution of gelatine. This solution should have a strength of about 1 oz of gelatine and about 9 gr of common alum in 20 oz of water. The paper must immediately be brought into contact with the moist image, and the excess of gelatine rapidly expelled by the squeegee before it has had time to set.

Any other support on which it is proposed to transfer the image finally must be coated with a solution of gelatine. The solution should be about 6 per cent strength, and it

should contain from 9 to 18 gr of common alum to each 20 oz of solution (1 to 2 g per litre). This preparation is specially necessary for opal glass, porcelain, ivory, celluloid, or wood. Wood should have the surface made perfectly mat with glass-paper. Before coating canvas prepared for painting, it is necessary to pumice-stone the prepared surface, wash it with a solution of soda to remove any grease, rinse it, and then apply two coatings of gelatine. It should not be stretched on a frame until after the final transfer of the image.

809. Final Transfer. The double-transfer paper should be cut rather larger than the actual size of the image, but smaller than the temporary support.

In order to avoid premature detachment of the image from a rigid temporary support through drying too rapidly, the final support is sometimes cut larger than the temporary support, so that the margins overlap and are folded and glued over the back of the glass or metal plate. If this premature separation occurs, it results in patches of greater or lesser gloss than the rest of the image.

About half-an-hour before the final transfer (an hour for thick papers) the double-transfer paper should be softened by immersion for a few moments in warm water. The temperature should be from 85° to 95°F, except in the case of paper that has been kept a long time, or paper of which the gelatine coating contains a large proportion of alum, when it may be from 104° to 112°F. The paper should then be placed in cold water, in which the gelatine will continue to swell. A few minutes before transferring, the temporary support bearing the image is also immersed so that the gelatine absorbs water. The gelatine-coated surface of the final support is then brought into contact with the image, care being taken to avoid air-bells forming between them. The temporary support with the final support clinging to it are brought out of the water together, placed in a firm position on a marble slab or a table, covered with a sheet of rubber, and the greater part of the water expelled by light strokes of the squeegee. The sheet of rubber should be lifted for a moment to ascertain that the final support is in the correct position. This check can be made by transmitted light if the two supports are translucent. The remaining water is then expelled by somewhat firmer strokes of the squeegee, and the print put to dry naturally. If the two supports are flexible,

hanging from a line is the best method; if either of the supports is rigid, a draining rack should be used.

Drying must not be too rapid, for there is a risk of the image leaving the final support, especially in the shadows. Drying too rapidly may also cause a glazing of the image in parts. If the air is very dry and the temperature high, it is well to slow the drying by keeping the print for several hours between moist blotting boards.

When the final transfer is made on any gelatine-coated support other than paper, the preliminary soaking in cold water will not require to be longer than 20 minutes, unless a large proportion of alum has been added to the gelatine.

After drying thoroughly, the print adhering to the final support should separate from the temporary support either spontaneously or by pulling it away gently, provided that the temporary support has been properly waxed. If both supports are flexible, they can be separated by drawing them under the edge of a ruler, as in straightening out a paper which has been rolled.

Any wax which adheres to the print may be cleaned off with a tuft of flannel moistened with benzene or petrol.

A carbon print can be glazed, after it is finished, by being re-wetted and dried on glass (§ 764).

810. Retouching and Colouring. Retouching or colouring should, preferably, be done before the final transfer. Prints made by single transfer can, obviously, only be retouched on their exterior surface. The retouching can be made to blend with the image by holding the print for a few moments in the steam issuing from the spout of a kettle of boiling water.

For retouching, any water-colours may be used, mixed in such a manner that they match the colour of the print. However, it is preferable to obtain from the makers colours prepared from the same pigments as those used in the manufacture of the pigment paper. Alternatively, the trimmings of the pigment paper before sensitizing will provide the necessary colour. A cold solution of alum should be applied to the pigmented gelatine with a small brush in order to avoid any spreading of the retouching during the final transfer.

Finally, a light tinting can be applied to the image before the final transfer. This colouring will be seen through the image after it is transferred. For this tinting, albumen colours are

most suitable; they may be diluted with a solution of alum.

811. Principal Failures in Carbon Printing. In addition to the failures common to all printing processes, already considered in §§ 766-80, the causes of, and remedies for the principal failures in carbon printing are listed below.

The Film of Gelatine Cracks or Splits. The pigment paper is too dry when unrolled for sensitizing or printing. It should be moistened by being kept for some hours in a cool damp place, or in a cupboard where several dishes of water have been placed.

The Gelatine Dissolves during Sensitizing. The bath is too warm, or the tissue has been allowed to remain too long in the bath.

Melting of the Gelatine during the Drying after Sensitizing. Due either to drying in too warm a place, or by keeping too long in the sensitizing bath.

Imperfect Adhesion between the Gelatine and the Support during Development. There are several possible causes of this defect. The pigment paper may have been soaked too long before transferring, or the margins may not have been protected, or insufficiently protected, by a safe-edge during printing. The gelatine may have become insoluble through very slow drying after sensitizing, or by being kept too long after sensitizing, or by a general exposure to light.

The Original Paper Support Refuses to Come away in Development. If the edges only come away the trouble is due to over-exposure, and it is advisable to try hotter water, or the addition of ammonia, or placing the print in a solution of ammonium persulphate. If the paper will not come away at all, even at the edges, the pigment paper has been fogged by general exposure to light.

The Print is too Weak. The cause is insufficient exposure in printing.

The Print is too Dark. Over-exposure. Hotter water should be used for development.

Blisters Appearing during Development. Due to air-bells imprisoned under the film.

The Image Washes Off. The causes may be the same as those of faulty adhesion to the support, or the print may have been transferred too soon, or there was insufficient rosin in the waxing preparation on the temporary support.

Markings and Reticulation. May be due to sensitizing and drying at too high a temperature, or rough handling with the squeegee, or transferring in water which is too hot or too alkaline.

Patches of Irregular Density. Usually due to

the original paper support being removed too late, and so protecting some parts of the image from the action of the water.

The Image Comes Away from the Temporary Support during Drying. This is due to insufficient rosin in the waxing preparation or too rapid drying.

The Final Support Refuses to Come Away from the Temporary Support. This is probably due to the temporary support not having been waxed; or the wax may have been removed in places by too much polishing, or the waxing solution may contain too much rosin.

The Image only partly transfers to the Final Support. This is due to the gelatine of the final support being insufficiently swollen in water before transferring, or being dissolved in places by immersion in water at too high a temperature.

Shiny or Silvery Markings Appearing in the Light Parts of a Print Produced by Double Transfer, after Drying. Due to faulty adhesion of the depressions of the print with the gelatine of the final support, through excessive swelling of the print before the second transfer.

CARBON PRINTING WITHOUT TRANSFER

812. The Artigue and Fresson Processes. Used for his own private work from 1878 by F. Artigue, a carbon paper to be used without transfer was placed on the market in 1894 by V. Artigue, under the name of "Charbon Velours." The coating of pigment is obtained by spreading on the paper, which is sized so as to stop-up the pores, a mixture of gelatine, sugar, and glucose. While this is still sticky, it is dusted over with a very finely divided pigment, according to a method of Beaugerard (1857) and of Blair (1863).

Similar results may also be obtained by incorporating the pigment in the mixture of colloids, using about 5 parts of pigment to 1 part of the mixture of gelatine and sugar, and coating paper with an exceedingly thin layer of this mixture; a similar process is employed in preparing the Fresson paper (1900), made in various tints on supports of different textures.

After sensitizing for two to three minutes in a weak solution of bichromate (2 per cent at the most for daylight printing), preferably neutralized by addition of ammonia (till the colour changes from orange to yellow), at a temperature not much above 60°F, the paper is dried in darkness, and printed under the negative in the usual way. There is no need

to mask the negative, and printing is timed by means of a photometer.

The exposed print is first soaked for several minutes in cold water, taking care to avoid air bubbles on either side of the paper, and then for a few seconds in tepid water, at a temperature not exceeding 86°F. Here the high-lights of the picture, protected during printing from the action of the light, swell and form an image in relief. During this immersion in the warm water, especially in the case of Fresson paper, there often appears a silhouette of the image, either negative (in the case of under-exposure) or positive (in the case of over-exposure). In either case the paper should be removed from the warm bath in order to be "developed" before the image becomes distinct.

For development, the print is laid on glass or other rigid support, held almost vertically, and laved from a wide-mouthed coffee pot, with a mixture of white wood sawdust (sifted through mesh No. 120) and water, in the proportion of 2 oz to 10 oz of sawdust to 20 oz of water. The mixture should be warmed to about 68°–75°F in a large tub, above which the print is held. The mixture of sawdust and water must be poured on to the upper margin of the print, so as not to attack too vigorously the image over which it flows. Wood sawdust may be replaced by kieselguhr (infusorial earth), which is much finer and less harmful to the light details (J. Desalme, 1922).

The slight friction of the sawdust on the previously swollen image drags away the pigment more quickly from the parts which are in greater relief and thus impedes the streaming, these differential frictions giving the modelling of the half-tones.

The same sawdust mixture may be used repeatedly, especially if an antiseptic is added. From time to time, it can be filtered on fine linen and washed with very hot water to free it from soluble matter.

The operator may use local control, by lightening certain parts with a stronger jet of the sawdust mixture squirted directly on, or by gentle touches with a brush or wet tuft of cotton-wool.

The image is somewhat tender, and should not be submitted to prolonged washing, so that it is best to eliminate the bichromate by immersion in a very dilute solution of sodium bisulphite, after which the print is briefly rinsed, and left to dry by hanging it on a line.

813. Papers Exposed through the Back. Attempts have been made from time to time to

revive the use, in pictorial photography, of ordinary carbon pigment papers, rendered semi-transparent with paraffin oil after sensitizing, and then exposed through the support (V. Blanchard, 1895).

The following working method, described by H. Kühn in 1921, under the name of "Leim-druck" (glue printing), has been used in Germany.

Sheets of strong glue are broken with a hammer into small pieces, and soaked in cold water, for about 48 hours. The excess of water is poured off, and the glue is dispersed in the water which it has absorbed. In a mortar or on a polished stone slab, are mixed, with a grinding muller, about 10 ml of this solution, 15 ml of a 10 per cent solution of ammonium bichromate, and 1 g of a very finely-ground black pigment (soft drawing crayon). If the mixture is too thick it may be diluted with a very little water.

A thin white or slightly tinted paper with smooth surface, and larger than the negative, is fixed to a board with drawing pins, and covered rapidly with the pigmented glue, using a large soft brush. The coating must be sufficiently thick, but not too thick, or it will crack in drying. Inequality of coating has no harmful effects so long as the coating is sufficiently thick in all parts. After drying, a very glossy coating indicates that the proportion of gelatine to pigment is too great; a too mat coating points to an excess of pigment.

When drying is complete, the gelatine side of the sheet is laid down on a glass slab, and the back is covered with liquid paraffin. This should be done with a tuft of cotton-wool in subdued light. At least two applications should be given. A few minutes are allowed to elapse after each treatment, and any excess of paraffin is removed with blotting-paper before exposure.

Since the exposure is made through the support, the final image will be reversed unless a reversed negative or a film negative is used. With many subjects, however, reversal does not matter.

The printing is best timed by means of an actinometer covered with a piece of the same paper employed as support, and similarly treated with paraffin.

When taken from the printing frame, the print is washed in cold water for about five minutes, then "developed" in warm water at about 85°F.

When drying is complete, the paper is cleaned by immersion for about three minutes in a grease

solvent, e.g. petrol, benzene, or, preferably, a non-inflammable solvent such as carbon tetrachloride.

THE GUM-BICHROMATE PROCESS AND ITS VARIATIONS

814. Gum-bichromate. Invented in 1858 by Pouncy, at a time when the only working methods in favour were those yielding absolutely sharp pictures with a structure imperceptible to the eye, the gum-bichromate process fell into oblivion until Rouillé-Ladevèze (1894), then R. Demachy, A. Maskell, C. Puyo, and many others showed the excellent use which could be made of it. Contrary to a widespread opinion, the gum-bichromate process does not necessarily need artistic handling. From a good negative it is capable of excellent prints without any personal interpretation. This method has been almost totally abandoned during recent years, in favour of methods employing greasy inks. It is to be regretted that such is the case in view of the success with which the process is still used.

It is best to use only raw pale Senegal gum, with the addition of a suitable antiseptic. The gum solution improves with age, and there is, therefore, no objection to preparing a quantity in advance. It is customary to employ the moist water-colours supplied in metal tubes, which have the advantage of being already very finely ground and which mix readily with the gum solution. It is possible to obtain pictures perfectly free from grain by using, instead of solid pigments, the indelible inks (Chinese inks and inks of all colours), used in commercial drawing (E. Quedenfelt, 1923).

The bichromate may be mixed with the pigmented gum solution before being spread on the paper. Some workers prefer, however, to impregnate the paper with a solution of about 10 per cent of potassium bichromate, and then to dry it, before coating with the mixture of gum and colour.

815. Preparation of the Mixture. Break up into small pieces, about 10 oz of gum and suspend it in a muslin bag in a 20 oz jar. Fill the jar with cold water and cover over to exclude dirt. The solution slowly becomes acid, and its viscosity decreases progressively. After two or three weeks, dissolve in it 20 to 25 gr of salicylic acid or thymol, in order to prevent fermentation. Some workers dissolve, with the gum, a little sugar (about 5 per cent of the weight of the gum) to increase the

permeability of the dry gum and facilitate development.

It is best to choose from a small number of mineral pigments of great covering power. For black, use lamp-black (ivory-black is often too transparent), the tint of which may be warmed with a little yellow ochre or burnt umber, or tinted with blue with a little indigo. For reds, use red-chalk and Venetian red, with some burnt sienna or burnt umber.

The average proportions of gum and bichromate are—

Gum solution, 50%	3 volumes
Saturated solution of potassium bichromate (8 to 10%)	1 volume

but will vary with the viscosity of the gum solution. For 1 volume of bichromate solution, 2 to 4 volumes of gum solution should be taken, according to its viscosity. The proportion of gum will, therefore, vary with its age. As a rule, the coating should contain as much gum as is compatible with the spreading of an even film (C. Puyo, 1903).

It is difficult to give figures for the proportion of pigments in the mixture, not only on account of variations in the covering power of the various pigments (or even of one pigment, bought from different sources), but also because of variations in the thickness of the film when coating.

As a rough guide, for black prints, the average proportion is 11 g of moist colour for 10 ml of bichromated gum. The proportion of variation should be such that the film appears dark-grey (somewhat tinted by the bichromate), and not black when coated thinly.

The mixture is made up on the basis that about 3.5 ml of pigmented mixture is required to cover a sheet 10 × 8 in. intended for pictures 9½ × 7 in.

The ingredients are mixed in a basin, with a hog-hair brush about 2 in. broad, and rather stiff. A drop of the mixture is placed on the paper and spread with the finger in order to judge the depth of colour.

816. Coating the Pigmented Gum. The paper must be sufficiently sized to prevent the colour penetrating. Most drawing papers are suitable, if given a further sizing with a warm weak mixture (about 1.5 per cent) of arrowroot or starch, spread with a large brush. Writing papers which are strongly sized with resin, are usually difficult to coat. Chinese or Japanese papers need delicate handling. For first attempts it is well to choose a paper of very fine grain but not too glossy.

Place a sheet of thick Bristol board (a Bristol board may be used many times for papers of the same size) on a drawing-board and fix the paper to be coated on this with four drawing-pins.

The brush is charged with the mixture, and lightly scraped on the edge of the bowl so that it contains as nearly as possible just the quantity required to cover one sheet of paper. It is rapidly drawn the long way of the paper, the trail of mixture thus deposited being immediately spread over the whole surface of the sheet of paper by cross movements, without leaving any bare spots. The excess of mixture is immediately removed, and the coating is smoothed over with a flat brush, either hog-hair or goat-hair, fairly thick and not too supple. The coating should now be uniform and it is finished by being smoothed with another similar brush which is used with less and less force on the paper, while the board is turned in all directions. (For this purpose the board may be placed on a coin.) Coating should not take much more than one minute; a little less if possible. The coating of the gum solution may be done with a spray gun. The preliminary sizing of the paper is then usually unnecessary (O. M. Powers, 1926).

The sheet dries in about 15 minutes. Hold it near a stove or pass it above a flame, if necessary, until the paper shows a tendency to crack.

Prepare only the number of sheets necessary for one day, or, at the most, for the next day.

817. Exposure and Development. As there is no transfer stage, printing is done under a negative in the usual way. Printing must be controlled with an actinometer. The time will depend on both the colour of the pigment and the thickness of the coating where it is thickest in the hollows of the grained paper. Thus, it also varies with the grain of the paper. A coarse-grained paper may need double the printing time which would suit a smooth paper. Finally, it varies with the age of the paper. Paper which has just been prepared should be exposed a little less than paper prepared during the previous day.

The finest blacks are obtained, as a rule, with very slight under-exposure. The print then develops in cold water in a very short time. Over-exposure gives harsh prints, with pronounced, and often irregular, grain.

Development must be carried out very shortly after exposure.

For straight-forward development, the print is floated face down in a dish of water, and

examined from time to time. The picture appears first for an instant as a negative, caused by differences of swelling, and begins to develop after a time which, according to the exposure and especially the age of the paper, varies from five minutes (fresh paper), to more than three hours (paper 24 hours old). Without troubling further about the print, except to remove it from time to time to change the water in the dish, development may be left to itself. It may take from three hours to more than 24 hours. If it is very slow, keeping the print in water for several hours after it is finished will do no harm.

When finished, the print is put to dry, avoiding contact of anything with the surface, which is very tender. In course of drying the definition of the picture falls off a little, owing to very slight spreading of the gum. Outlines lose some of their sharpness, but otherwise retain their character. Some workers destroy any excess of bichromate by immersion in a very dilute solution of sodium bisulphite, and, after a brief rinse, pass the print through a bath of alum to harden the gum a little.

818. The chief merit of the gum process lies in the fact that it gives an artist the power to improve a subject by lessening or suppressing excessive details, and introducing accents here and there. Such treatment can be carried out during development, during drying, or after drying.

There is always an advantage in starting development as above, postponing any alterations until the picture is distinctly visible. Then, by placing the print on a glass or other firm support, the development of certain parts may be hastened by sprinkling with tepid water, from a jug, or with a sponge squeezed out above the parts to be lightened. In small sizes a brush, charged with cold or warm water, may be used but, for any small degree of lightening, and for all alterations to the principal subject, it will be found better to wait until the print is half dry, as the gum is then much more resistant.

After each local treatment, rinse with plenty of water in order to carry away particles of coloured gum which have been detached. For deepening of tones, colour taken from the margins of the print is used.

With an under-exposed print, in which the gum adheres very slightly to the paper, it is best to let the print first get completely dry. The gum is thus hardened, and the print may

be moistened by a few minutes' immersion in water before proceeding to the retouching.

819. Multiple Printing. A process often used (and sometimes abused) consists in superposing in register, on the same sheet of paper, several impressions in the same colour, or in different colours. Each partial image must, obviously, be kept much less dense, and, consequently, the proportion of colour to gum should be less.

To allow easy registration of successive impressions from the same negative, the latter is held in a cardboard holder, from which protrude the points of three or four drawing-pins, pushed into the card on the side corresponding with the back of the negative. The cardboard should be recessed a little, so as to accommodate the heads of the drawing-pins, and thus the paper is perforated by the points of the pins and is held in the same place on the negative during the repeated printings. The paper must be backed with felt, thick enough to prevent contact of the pin-points with the hinged back of the frame (F. Grandmaitre, 1923).

After the development of each impression, the print is put aside to dry thoroughly. The next gum layer is coated, and the print is replaced in the frame for the next exposure, so that the perforations of the sheet re-engage with the drawing-pins.

820. Bichromated Wash-drawing. This interesting variation of the gum-bichromate process is particularly suitable for obtaining large pictures, by printing under enlarged negatives.

A drawing-paper is first sized with a very thin film of weak gelatine solution. The beginner should choose a paper with fine grain. For this, the following mixture is used—

Crystallized sugar	4 g
Soft photographic gelatine	4 g
Water	100 ml

prepared by allowing the gelatine to swell in the sugar solution, and dispersing it over a water bath below 115°F. The sizing is preferably done in a room at a temperature of at least 70°F; the paper should then be at the same temperature as that of the room. It is fixed with drawing-pins to a drawing-board, placed level, and the gelatine solution poured on the centre in the proportion of 1 ml for each 16 sq in. of surface to be covered. The solution is spread with a swallow-tail brush, previously impregnated with the gelatine solution, and squeezed out on its edges. The solution is driven into the pores of the paper by vigorous operation of the brush, spreading it evenly until

the sizing has a mat appearance. The sheet is then passed through the steam from a pan of boiling water till the gelatine becomes uniformly glossy. In the interval between the two sizings the brush is held in the steam to prevent the gelatine in it from setting.

Now, put 1 g of de-greased lamp black (choose a black of brownish tint) on a piece of glass placing the powder in the form of a crater. Then pour into this 2.5 ml of a 50 per cent solution of gum arabic; mix thoroughly with a flexible knife, adding gradually 2 ml of water. Grind with a glass muller for about 10 minutes, until the mixture becomes perfectly even. To cover a sheet of paper 20 in. \times 26 in., about 2 g of this paste is placed in a clean cup, and about $\frac{3}{4}$ in. of the strip delivered by a tube of sepia water colour is added. This gives a warmer tone, and, at the same time, improves the adhesion of the coating. Now add from 15 to 18 ml (the smaller quantity in cold and damp weather, the larger in warm and dry weather) of the following mixture, prepared with boiling water—

Crystallized sugar	2 g
Starch	2 g
Water	100 ml

After mixing thoroughly, this paste is placed at the centre of the gelatine-coated sheet and spread with the swallow-tail brush previously charged with water. When the colour begins to thicken, a flat goat-hair brush is used to finish off the coating, the first stroke of this brush being at right angles to the last stroke of the swallow-tail brush, so as to break up the streaks. Continue in this way until the sheet is surface-dry, and then leave to dry thoroughly by hanging from stretched cords.

The sensitizing is done, as required, by immersion in a 1 per cent solution of ammonium bichromate, with the addition of 1 per cent of neutral sodium or potassium citrate.

The negatives best suited for this method of printing have a density range of about 1.3.

The exposure should be about equal to that required to make a P.O.P. print for toning and fixing.

Before development, the print is immersed face downwards for about 10 minutes in a dish of water at 115°F, taking care to avoid adhering air bubbles. As the water slowly cools down, the print is moved about from time to time. The print is then fixed to a rigid support, sloped to about the angle of a painter's easel, and development is begun by squirting the

surface with water at a temperature of about 18°F above that of the soaking water. This may be done with a toilet spray or an air brush. The spray is held from 12 in. to 16 in. from the print, and the water is squirted all over the surface. The development may be localized as required by bringing the vaporizer nearer. Development takes about 20 minutes for a surface 9 \times 5 in. which has been correctly exposed.

PRINTS BY DYEING FILMS OF BICHROMATED GELATINE

821. General. If bichromated gelatine is coated on a support impermeable to aqueous solutions, dried, exposed under a positive, and then rinsed with water to remove excess of bichromate, aqueous solutions of certain dyes will penetrate the gelatine where it has been protected against the action of light, but will not penetrate the more hardened regions. The dye absorbed by the gelatine thus forms a continuous-tone positive image. (E. Edwards, 1875; C. Cros, 1880).

Similarly, a gelatine relief, obtained in the same way as a carbon print, but by means of unpigmented gelatine (A. Chardon, 1875), may be transferred to a support, or made on an impermeable film support, and dyed uniformly by means of dyes, which are readily fixed by almost impermeable gelatine. In this case, as in making a carbon print, a positive is obtained by printing from a negative. The latitude (straight-line portion of the characteristic curve) becomes considerably greater when the penetration of light into the film is impeded by the presence of an absorbent substance. The contrast tends to be less, but this can be remedied by using a stronger dye bath. The maximum latitude is obtained only after long immersion (24 hours or more), the penetration of the dye being very slow in the most strongly tanned parts (A. C. Hardy and F. H. Perrin, 1928).

It was found by Cros that the dye thus absorbed by the gelatine could be transferred to moist paper placed in contact with it. One film of gelatine is thus able to give a number of prints if it is re-dyed after each transfer. He gave this process the name of *hydrottype*. Sanger-Shepherd (1902) made a similar observation in the case of images obtained by dyeing a gelatine relief, using a paper coated with very soft gelatine for taking impressions. L. Didier (1903) worked out the dyes best lending themselves to selective absorption on undeveloped

gelatine, and to the subsequent "printing" by contact with gelatine-coated paper. This method was put on the market under the name of *Pinatype*.

These methods are employed chiefly for obtaining multicolour transparencies for use as advertisements and for the production of three-colour pictures on paper. By using a black dye with the Pinatype process, *reversed negatives* or *positives* may be made in one operation.

The images thus obtained, even when the further precaution is taken to mordant the dyes absorbed by the gelatine, are never quite fast, and so should never be exposed to the direct sun.

822. Imbibition without Development—Pinatype. Fogged or doubtful plates may be used after removal of the silver bromide. After fixing with hypo and washing, the plates are dried, then sensitized in a 2.5 per cent solution of ammonium bichromate (neutralized by the addition of ammonia until it turns bright yellow), and then put aside to dry. Alternatively, the glasses from waste negatives may be gelatine-coated. The cleaned glasses are first coated with a very weak solution of sodium silicate (commercial solution diluted about fifty times with water) in order to increase the adhesion of the gelatine to the glass, drained, and dried. The glasses are then levelled, silicated side upwards, and coated with a solution of hard gelatine (4 per cent for transparencies or 8 per cent for a Pinatype printing plate) in the proportion of 50 to 65 ml per sq ft. After drying, the gelatine-coated plates are sensitized in the bath given above.

After exposure under a positive transparency (or under a negative when making a duplicate negative), the plates are washed for five minutes. The exposure should be controlled with an actinometer. To avoid diluting the dye, the plates are best dried before dyeing.

When it is not desired to print the image by transferring the dye to sized paper, the dyeing may be done in approximately 2 per cent solutions of one or another of the following dyes (L. Lemaire, 1911), or in suitable mixtures of these dyes—

Red:	Croceine Scarlet, Kiton Red 6B.
Yellows:	Lissamine yellow, quinoline yellow.
Green:	Naphthol green.
Blue:	Diamine blue.
Violet:	Lanacyl violet.
Bluish or purplish blacks:	Naphthol black, naphthaline black, amine blacks.

For transfer of the image to paper, use is

made of the dyes given below. These are equally suitable if the image is not to be transferred.

Red:	Dilute 3 to 4 g of natural carmine (cochineal) with a very little distilled water, add just enough ammonia to dissolve—2 to 5 ml—and add distilled water to make 1000 ml.
Blue:	3 per cent solution of pure diamine blue or benzoine blue BB.
Green:	3 per cent solution of naphthol green B.
Yellow:	3 per cent solution of thioflavin S, acidified with a little citric acid.

After soaking in the dye bath for about 10 minutes, the plate is briefly rinsed. A small squeegee is used to apply to it a sheet of sized paper (soft gelatine, with no alum, or very little), e.g. double-transfer paper, as used in the carbon process, which has previously been soaked in cold water. This is covered with moistened blotting-paper, then with rubber sheeting to prevent drying, and is left for 10 to 15 minutes, during which time the colour passes from the hard to the soft gelatine. From time to time a corner of the paper may be lifted for examination, taking care to replace the two gelatine surfaces immediately in contact.

For further prints, the dyeing of the plate will only need three minutes.

Whether direct dyeing of the positive transparency or transfer to sized paper is used the dye must be fixed on the gelatine by immersion for about five minutes in the mordanting bath—

Chrome-alum . . .	2 g
Copper sulphate . . .	2 g
Water to make . . .	100 ml

and then rinsed for about five minutes.

Images obtained by transfer from one layer of gelatine to another always lose some sharpness owing to the lateral spread of the dye unless the receiving gelatine has been uniformly mordanted (R. von Arx, 1927). It has been suggested that this mordanting be effected by dipping the gelatine-coated paper in a solution of aluminium sulphate or alum, and then in a buffer solution of sodium acetate, the success of the transfer depending essentially on the degree of acidity of the gelatine receiving the image (M. W. Seymour and A. Clair, 1936). Processes utilizing the transfer of a dye are usually rather difficult to control; their commercial application always demands delicate adjustment.

823. Dyeing of Gelatine Reliefs. To obtain reliefs for dyeing, suitable material is gelatinobromide (celluloid) film without gelatine coating

on the non-emulsion side. This is sensitized with bichromate, exposed under a negative through the back (the uncoated side of the film against the emulsion side of the negative), developed in warm water, the silver bromide removed in a fixing bath, and dried. The relief so obtained may be dyed by immersion in solutions of a very large number of acid dyes.

For the preparation of a carbon pigment paper readily permitting of the superposition of several component images, the process described in 1901 by A. and L. Lumière may be used.

A sheet of glass is polished with talcum powder (French chalk), and the edges then coated with thin rubber solution.

When the rubber is dry, the glass is coated with enamel collodion, and, after drying the collodion, a sheet of clean paper is applied to the coated side by means of a solution of gelatine, warmed to 120°F, into which the paper and the glass are placed. The two are brought into contact in this solution, and the excess is immediately expelled with a squeegee.

After drying, the paper is coated with white varnish, diluted with an equal volume of alcohol, and left for about 12 hours to dry. The paper, still secured to the glass, is now ready to receive the bichromate mixture, temporarily tinted with cochineal—

Gelatine, emulsion quality . . .	120 g
Pale strong glue . . .	120 g
Ammonium bichromate . . .	60 g
Potassium citrate . . .	10 g
Cochineal red . . .	1 g
Alcohol . . .	200 ml
Water . . .	1000 ml

This mixture, filtered through muslin, is coated on the levelled plates, in the proportion of 50 to 65 ml per sq ft. When the gelatine has set the plates are placed on racks and dried in the dark in a current of air. The drying conditions should be kept constant, any variation being liable to produce coloured areas in the final picture. After drying, the papers are removed from the plates that have served as supports.

Following exposure under a negative (controlled by an actinometer), the paper is transferred to a collodion-coated glass plate, prepared according to the formula above, and then covered all over with a very dilute solution of rubber (7 g per 1,000 ml).

Before development, the transfer is left in cold water for about two hours to allow the gelatine to swell uniformly; the development is carried out at between 95°F to 104°F; when the

development is finished the picture is decolorized, and then presents the appearance simply of a very slight relief. It is then washed in cold water, and put aside to dry.

For the dyeing use may be made, among other colours, of the following baths (three-colour dyes, A. von Hübl, 1912) or mixtures of them—

Rhodamine S.	0.25 g		
Solid bluish green Bayer	—	1 g	
Naphthol yellow	—	—	0.5 g
Alcohol 90°	100 ml	100 ml	100 ml
Glacial acetic acid	—	5 ml	5 ml
Saturated chrome-alum solution	—	—	50 ml
Water to make	1000 ml	1000 ml	1000 ml

After the dyeing, which, at the dilutions given, may take several hours, the excess of dye is removed by a brief rinse.

When there is occasion to superimpose several component images, the final effect may be judged by packing the plates bearing these images in two wooden blocks, placing the whole well above an opal glass or white paper. The necessary corrections, general or local, may then be made by fresh dyeing or by decolorizing with water rendered slightly alkaline with ammonia. Each of the pictures is then mordanted, as previously described, rinsed, and put aside to dry.

The dried images are coated with a 1.5 per cent solution of rubber, then with a 1 per cent solution of collodion. To superimpose the pictures, use is made of a temporary support, prepared as indicated below, cemented to one of the pictures with a 15 per cent solution of strong glue. After complete drying, the paper is removed, bringing the print with it. This latter is applied on the next image by means of an alum-gelatine solution, made as follows—

Hard gelatine	120 g
Glycerine	50 ml
Chrome-alum, 10% solution	10 ml
Water to make	1000 ml

The two images are registered through the glass and a squeegee is used to remove any excess of gelatine, and the whole is left to dry. The paper, carrying with it two pictures, is then removed, and the process repeated for the succeeding image. This method may be used to transfer the whole series of the pictures to glass, or to keep it as a film. In both cases the paper may be detached from the block of images by immersion in warm water, which dissolves the glue but not the hard gelatine.

DUSTING-ON PROCESSES

824. General. Garnier and Salmon showed in 1850, that a thin layer of albumen, sugar, and bichromate, coated on glass, dried, and exposed under a positive transparency, will retain image-wise mineral substances in powder form dusted on the surface. The powder does not adhere to parts sufficiently modified by the action of the light. The tone rendering obtained by this process is very satisfactory.

With some minor modifications, this method has been regularly used since then for the production of *photographic enamels*, and for the photographic decoration of ceramic goods. In this case, powdering is done with vitrifiable glaze colours. Vitrified photographs are unaffected by atmospheric conditions only if the "flux" used is not too rich in lead salts (which would gradually turn black by sulphiding) and contains only a small proportion of soluble salts (borax, etc.), which are sometimes used to lower the melting point.

The method is suitable for making direct duplicate negatives or positives. It also provides a means of intensifying negatives or positives without affecting the original image in the least. It is for these latter purposes that it is described below.

Some years ago R. Namias (1922) resuscitated a process used in 1879 by A. Sobacchi for copying tracings, and applied it to pictorial photographic printing (*resinopigmentype*); a similar process was brought out by E. Buri (1924).

825. Direct Reproductions by the Powder Process. The sensitizing solution is made up in cold water as follows—

Gum arabic	50 g
Sugar	100 g
Water to make	1000 ml

to which may be added antiseptic, e.g. 2 g of salicylic acid. At the time of use, the required quantity of this liquid, which must be quite clear, is mixed with a quarter of its volume of a 20 per cent solution of ammonium bichromate. This mixture is coated in a thin film on a clean glass. The excess liquid is drained off, and the plate is dried by holding it, coated side uppermost, over a gas ring until the coating is no longer sticky to the touch. Before the glass has quite cooled down, it is placed in a frame under the negative (or positive transparency), which should be perfectly dry, and exposed to light.

As soon as the exposure has been given, the plate is supported above a sheet of white paper, against which the development of the image is watched. Care is taken not to breathe on the sensitive coating. To prevent this, a piece of glass may be held in front of the operator.

A large, very soft, and perfectly dry badger-hair brush is dipped in the finest powdered graphite, which should have been dried for some minutes in a metal container on a stove. The brush is then drawn very lightly in all directions over the sensitive surface.

The image gradually appears as the portions of the layer which were protected from the action of light absorb moisture from the air. The contrast of the image will not increase beyond a certain point after which the powder begins to adhere uniformly all over the surface. Powdering should be stopped before this point is reached and the image is immediately given a coating of collodion.

The same method is used in intensifying a negative, the sensitive coating being applied on the surface of the image, which has been previously varnished.

The method may also be used for obtaining positive images by printing from a negative on a black support. In this case, powdering is done with a white or very light powder such as aluminium or bronze powder.

826. Resinopigmentype. The material used is a smooth paper base, heavily coated with hardened gelatine. This is sensitized by immersion for two or three minutes in a 5 per cent solution of ammonium bichromate.

The sensitized paper is exposed under a positive transparency until a weak negative image in brown on a yellow ground is seen on the paper.

The print is left in water, which is renewed several times, for long enough to remove all colour from the background, on which appears an extremely weak yellowish image. The print is then placed in hot water (about 120°F) until it shows well-marked relief. This takes two to three minutes. If the paper has been sensitized several days beforehand, it is necessary to add 1 to 2 per cent of ammonia to the warm water. The print is then laid face down on several thicknesses of blotting-paper, and dried with filter paper or with a pad of butter muslin.

Immediately afterwards the image is powdered with a specially prepared pigment mixture. This is made by grinding and powdering a mixture of rosin and wax with a suitable

pigment (lamp-black, mineral colours, etc.). The mixture is spread with a very soft round brush and carried over the surface of the gelatine in circular movements, pressing harder on those parts where it is wished to increase the density of the image. Excess powder is swept away with the same brush, and any working-up of the shadows is then done with a somewhat stiffer brush.

In case of lack of contrast, the print is put in cold water, and powder is removed by friction with a cotton pad. The powdering is then repeated, after having passed the print again through hot water, with the addition, if need be, of a stronger dose of ammonia, to increase the swelling.

As the pigment adheres very lightly to the damp print, retouching is easy at this stage by erasure with a moistened brush, after blotting off. However, it is as well to *dry the print first* and then to remove the last traces of bichromate by immersion in a very dilute solution of sodium bisulphite, followed by a quick rinsing. After drying, erasing may still be done with india-rubber or an erasing knife.

The colour may be fixed by passing the dry print through steam from a vessel of boiling water. The colours set without making the print glossy. Alternatively, the print may be sprayed with a clear, spirit varnish.

PRINTS IN GREASY INKS ON BICHROMATED GELATINE

827. General. The process of making prints in greasy inks on bichromated gelatine is known as the Oil Process and was introduced for use in pictorial photography by G. E. H. Rawlins in 1904. It is, in fact, only a variation of methods used since 1855 in various photo-mechanical processes such as collotype and production of prints for photo-lithographic transfer. The process consists of exposing a layer of bichromated gelatine under a negative and washing it in water to swell those parts which have been protected from exposure. Owing to the mutual repulsion between water and greasy substances, the ink takes only on the least swollen parts of the image.

In the Rawlins method the crude and mechanical action of the ink roller is replaced by inking with a brush, which is easy to control and to localize. In the hands of an artist this is a method of wonderful elasticity, and can yield prints of great beauty. Nevertheless, there is the layer of gelatine which forms the support

of the image. This drawback has been removed (R. Demachy, 1911) by transferring the image to plain paper of a quality usually used in art copper-plate printing. The gelatine-coated paper on which the image has been made thus plays the part of a printing plate.

The image, printed from a negative in the normal way, is correct, as regards right and left, on the gelatine-coated paper. Thus, it is reversed by the transfer. Where it is important for the picture to be the correct way round the print should be made from a laterally reversed negative. Alternatively, the ink may first be transferred to a rubber blanket and then re-transferred to paper (J. Rowatt, 1922).

828. Materials and Apparatus. The gelatine-coated paper is generally chosen from among double-transfer papers for the carbon process avoiding those which are stiff or which have a glossy surface.

Beginners should choose smooth or mat papers rather than grained ones. When the ink is to be transferred, only smooth-surfaced papers can be used. The paper should be cut so as to allow a margin of about $\frac{1}{4}$ in. all round the subject. Inking cannot satisfactorily be done up to the edges of the sheet.

The inks supplied on the suggestion of Rawlins for use in this process were very fluid and quick-drying. They covered the paper almost uniformly if the gelatine was only moderately swollen. Gradation was then obtained by removing the ink by tapping with a dry brush. Soon afterwards, R. Demachy and C. Puyo recommended the use of two types of ink of different consistencies. By using mixtures in different proportions according to the degree of swelling of the gelatine, it is easy to ink the image without having to remove any ink which has once been applied. A very hard ink such as is used for lithographic machine printing, and a relatively fluid ink as used for copper-plate printing are suitable for this technique. These inks are manufactured in all shades. The beginner will be wise to limit himself to blacks, which may be made warmer by the addition of a little burnt sienna, or colder by a little ultramarine blue. Copper-plate inks are supplied in metal tubes of the kind used for artists' colours. Lithographic inks are harder and can only be packed in tins.

Inking is done with polecat-fitch brushes shaped like a hind's-foot of diameter appropriate to the size of image to be inked. The inks are mixed on a piece of glass, using an

artist's straight palette knife, or, failing this, an old, flexible-bladed table knife. For the inking operation, the print is placed on a bed of several thicknesses of damp blotting-paper on a piece of plate glass.

829. Sensitizing and Exposure to Light. The paper may be sensitized by soaking in a 2 per cent aqueous solution of potassium bichromate. The sensitized paper keeps only for about 48 hours.

In spite of the fact that negatives of various contrasts can be printed by this process, it is desirable to start with those of medium contrast.

Inking with litho ink is only possible with a print which has had an exposure much longer than would be suitable for inking with copper-plate ink. Between these two limits all times of exposure will be satisfactory provided that a suitable mixture of inks is used.

Although the image appears in pale brown on the yellow ground of the paper it is not easy to judge the exposure by this and it is therefore desirable to use an actinometer.

830. Washing, Swelling, and Drying. As soon as possible after exposure to light, the paper is washed in several changes of water until nearly all colour has been removed and is then placed in a solution of sulphuric acid of about 1 per cent where the paper will be completely decolorized in two to three minutes. The print is then rinsed in several changes of water. In this condition the sheet may be inked, or the inking may be indefinitely postponed. In this case it will only be necessary to re-moisten the dry sheet of paper.

To condition the gelatine for inking, it should be swollen until the relief is plainly visible. This swelling may be done by immersion in tepid water (77°F to 86°F) or in cold water to which has been added 4 per cent to 10 per cent of ammonia; this is brushed over the surface of the gelatine.

After suitable soaking, the print is placed on the bed of moistened blotting-paper, where it will adhere, and dried by wiping (not by dabbing, which might leave rough spots) with a pad of chamois leather or an old handkerchief.

831. Inking the Print. In two opposite corners of the palette are placed small dabs (about as large as a pea) of litho ink and of copper-plate ink. These dabs of ink are then smoothed out with a knife.

The inking brush is pressed on the mass of hard ink, then tapped gently on a clean part

of the glass in order to distribute the ink evenly throughout the brush. The brush is pressed flat on a part of the print which includes both a black and a white, pressing slightly up and down and at the same time turning it lightly round in the fingers, but without letting the hairs lose contact with the gelatine. If, on raising the brush, it is seen that the image is correctly rendered, with full blacks and nearly clean whites, and if the proper gradation can be obtained by light tapping, it may be concluded that the exposure and the swelling suit the litho ink and the inking may be completed with it.

If the blacks do not come up, and if the tapping results only in removing ink from them, the exposure has been too short for use of the litho ink, or the swelling has been excessive. Successive mixtures of litho ink with various proportions of copper-plate ink should then be tried, at first very small, then more and more, until inking takes place easily. If, it is found necessary to use copper-plate ink almost pure, the print is probably too damp.

In this case, the ink should be cleaned off and the print dried. It can then be re-swollen, this time to a lesser degree.

On the other hand, should the gelatine be covered more or less uniformly with hard ink, the exposure may have been excessive, or the swelling insufficient. Further swelling may be tried, but the result will probably be of mediocre quality.

It is always best to begin inking in the most important part of the picture. After application of the ink by the gliding and twisting of the brush, a light tapping takes away the excess of ink in the whites and causes it to penetrate the shadows. A very similar result may also be obtained by a rapid sweeping with the tips of the hairs. Portions of the picture of less interest are then lightly brought up with a brush almost free of ink, then progressively strengthened to the required density.

At any moment the work can be wiped out with a pad of cotton-wool soaked in petrol, followed without delay by a soft sponge well charged with water. After this, the print may be replaced in warm water to swell, or in ammoniated water.

Alterations in the composition of the ink allow various depths of tones to be obtained and controlled at will. Parts treated with the soft ink may be lightened by tapping with a brush charged with hard ink. This will restore the

lost contrast, by virtue of the greater stiffness of the ink resulting from the mixture.

Pure whites may be made with a small brush wetted with water. Shadows may be obtained with a brush which has been charged with petrol. The flat tone which results is afterwards modelled by tapping.

Hairs and particles sticking to the picture are easily removed by touching them with a hard rubber, shaped to a point. The same rubber is also useful for obtaining pure white accents.

After each stage of the inking process the brushes should be well cleaned with petrol. After rinsing, they should be hung up, hairs downwards, to dry.

832. Drying and Cleaning the Print. Ink images on a layer of gelatine dry very slowly. Thus, the print remains in a tacky state for a very long time, and contact of anything with the image is liable to remove the ink or to smudge it. In order to dry it, the print should be pinned by the four corners to a wooden board or a stout card, and left for several weeks.

After drying for at least a week, the print may be immersed in a dish of grease solvent, such as petrol or carbon tetrachloride, for a few minutes. Care must be taken that nothing touches the surface of the print which is then drained and dried. This treatment leaves the image mat and makes it much less susceptible to abrasion.

833. Obtaining Prints by Transfer. Although a good oil print may be made on any paper with an unhardened, mat gelatine coating, only papers with a fairly thick coating are suitable for making prints to be transferred. The gelatine must give a very strong relief and it is therefore helpful to use negatives of fairly high contrast.

A print inked with litho ink never transfers so well as one inked with copper-plate ink. Although the image may be satisfactory, it does not follow that the transfer will be. The full quantity of the ink never transfers and the efficiency of transfer is usually less when the ink is hard than when it is soft. Copper-plate ink, stiffened with a very little litho ink, if necessary, is generally satisfactory.

When several transfers are taken from the same print, inked each time with the same ink, it is found that the contrasts increase from one print to the next. Even if the first print is a little grey, the fourth print will probably have blacks so dense that all detail will be lost.

This is because the gelatine absorbs more water after each passage through the press, with proportionate increase in the relief of the image. Indeed, to obtain this effect it is not necessary to make actual transfers; the gelatine-coated sheet between two clean pieces of porous board may be passed several times through the press until eventually it absorbs so much water that it cannot be inked, even with copper-plate ink. This "blank printing" is often employed for facilitating the inking of prints intended for transfer.

834. Papers for Transfer Printing. Transfer may be made on most papers, but it is easier to get good results on the unsized or half-sized papers generally used for printing artists' proofs from copper-plates.

For press transfers, the unsized or half-sized papers should be dampened. Sized papers are generally used dry, with the exception of drawing papers, which are slightly moistened.

For transfer of prints about 10 × 8 in. without a press, the paper does not usually need to be moistened.

Printing on damp paper always slightly reduces the contrast.

In case of urgency the sheet to be moistened is dipped in water, drained, and wiped between two smooth blotting boards, preferably by passing through the press. When a number of prints are to be made, the following is a good method. A piece of zinc or glass larger than the paper is placed flat on a table; on it are placed in succession a dry sheet, a sheet wetted by immersion in a dish of water, two dry sheets, a wet sheet, and so on, finishing with a dry sheet. The pile is covered with a piece of zinc or glass, and a weight is placed on top. In a few hours moisture spreads uniformly throughout the pile, and the paper will remain in condition for several days.

The paper may be wetted with liquids other than water in order to facilitate transfer with minimum pressure. This is useful when prints are required on grained paper without the grain being crushed. Petrol is suitable for this purpose (R. Demachy, 1933).

835. Press Transfer. For the transfer a lithographic press or a copper-plate press may be used. For prints of small size it is possible to use a copying press or a dry-mounting press. If a press is to be bought specially, the most suitable are small models of copper-plate presses used by engravers for taking proofs. On the bed of the press, one or two thicknesses of

woollen blanket are laid. These should be the same size as the bed. After unscrewing the tightening screw and lifting the upper cylinder by means of blocks slipped under the cylinder bearings, the bed is placed between the cylinders, taking care that its long sides are at right-angles to the axes of the cylinders. The upper cylinder is allowed to fall back on the blanket pad and the two screws are tightened equally. The hand-wheel is turned so as to engage at most a quarter of the length of the bed between the cylinders. The blankets are now raised and an assembly is made on the bed as follows—(i) a piece of blotting-board at least $\frac{1}{4}$ in. larger than the printing paper; (ii) the inked print, face uppermost, centred on the blotting-board (the edges of the print should have been cleaned, if necessary, with a wad of damp cotton-wool); (iii) the printing paper, face downwards, centred on the blotting-board; (iv) a second blotter of the same size as the first. On this blotter the blankets are pressed down, one by one, smoothing them at the same time. The hand-wheel is turned, slowly but continuously, until the sheets of paper are completely conveyed to the other side of the cylinder. The blankets are then lifted and the papers withdrawn. Once the print has been started on its passage through the press, the handle must be turned continuously as the slightest pause will cause a mark.

836. Transfer Without Press. The transfer of the image on to its final support may be done without a press by rubbing with the back of a spoon or similar hard, smooth tool. It is necessary to go over every part of the image several times, crossing the paths of the tool used. The printing paper should be lifted partially from time to time to judge the progress of transfer. Care must be taken to replace the paper in exactly the same place each time. Not only is this work tedious for a sheet of large size, but there is a risk of the paper not falling back exactly into its original place, thus giving rise to a double image.

VARIOUS PROCESSES

837. Ozotype. A variation of the carbon process was devised in 1899 by T. Manly. This process, however, has been abandoned since the introduction of the Ozobrome process described in Chapter XLVI.

A sheet of single-transfer paper (§ 800) is sensitized in a solution of potassium bichromate, dried, and exposed under a negative until all the details in the image are visible. A sheet of

carbon pigment paper is immersed for about a minute in a bath of—

Acetic acid, glacial	3 ml
Hydroquinone	1 g
Water	1000 ml

The print on bichromated paper is rapidly placed in this bath, and applied to the carbon pigment paper. The two are withdrawn together, the liquid between them is drained off, and the two sheets are left between blotting-paper to dry. After drying, they are together placed in cold water for about half an hour, after which development is carried out as in the single-transfer carbon process.

The chromium chromate, formed in the single-transfer paper during its exposure to light, is decomposed by the acetic acid, liberating chromic acid. This is absorbed by the incompletely-swollen carbon tissue and is reduced by the hydroquinone in the coating of pigmented gelatine. The products of this reduction tan the gelatine so that after development it remains adhering to the single-transfer paper (A. Haddon, 1901).

838. Dye Prints by Photo-mordants. A piece of fabric which has been well washed and dried, is soaked in a solution of potassium or ammonium bichromate, drained, and dried at a low temperature. It is exposed under a negative till a brown image appears and then washed until the background is colourless. The image, which is nearly invisible, is then formed of chromium hydroxide, which can act as a mordant for numerous dyes. For example, the mordanted material may be placed for from ten to twenty minutes in a boiling solution of alizarine, for red or violet; or of alizarine blue, orange, or black, or anthracine blue or brown, or gallein, coerulein, galloflavine, etc. (Persoz, 1857; E. Kopp, 1863; A. Villian, 1892). After dyeing, the fabric is rinsed, and the whites are brightened by washing in hot soap and water and, if necessary, cleared in a solution of sodium hypochlorite.

Instead of using ready-prepared dye, a dye may be formed by oxidation of suitable organic substances by means of the chromic acid available in the chromium chromate, formed during exposure to light. The operation may be carried out in the cold, and this process is, therefore, applicable to sized or unsized paper. The paper or fabric is sensitized with bichromate and, after exposure under a negative, is washed in several changes of water acidified with 0.1 per cent of sulphuric acid. It is then

immersed in a very dilute solution of one of the following substances, together with a little sodium bisulphite (1 to 2 g per litre of each constituent) paraphenylenediamine, par-aminophenol, pyrogallol, or other polyphenols or polyamines (E. Kopp, 1863; Andresen and Gusseron, 1899).

839. Prints with Diazo Compounds. Several printing processes are known under the general name of *diazotype*. They are based on the destruction of diazo compounds by light, and on the property possessed by these substances of producing azo dyes by coupling with a phenol or an aromatic amine. These dyes are fixed on cellulose (paper, cotton, etc.) without a preliminary mordanting.

These processes may be classified as follows (D. A. Spencer, 1928)—

1. The diazo compound *A* when decomposing in light, produces a substance *B*. Development is effected in an alkaline solution by a coupler *C* which gives with *A* a coloured compound that is insoluble and does not react with *B* (A. Green, C. F. Cross, and E. J. Bevan, 1890). For instance, a fabric dyed with primuline is diazotized (its colour changes from yellow to reddish) and dried in darkness. After exposure to light under a positive the image is fixed and intensified by coupling in a solution of β -naphthol made alkaline with caustic soda. A red image is thus obtained. In all processes where the image is formed by decolorization, penetration of the sensitizer into the thickness of the paper should be avoided, since the sensitizer would then be incompletely destroyed and would give rise to a general tint of greater or less depth.

2. The diazo compound *A* decomposes and produces a substance *B*. Development is effected by applying a substance *C* which with *B* gives a coloured product, but does not react with *A* (G. Koegel, 1926). For instance, a paper sensitized with a diazo compound is exposed under a negative and then treated with an ammoniacal solution of silver nitrate which develops a positive image of reduced silver.

3. The sensitizer is a mixture of the diazo compound *A* and coupler *C*. Reaction between them is prevented by the addition of an organic acid. Such papers can be developed by exposure to ammonia vapour without fixing or washing (G. Koegel, 1916-1922), or by wetting

superficially with a very dilute alkaline solution. For making copies of tracings (positive images with brown or purplish lines on a slightly tinted ground) *Ozalid* paper is commercially available, and cellulose acetate film is sold as *Ozafilm* for copying X-ray negatives and cinema film. The process of dry development obviates any distortion of the support by wetting and consequently any variation in the scale of the copies. The ammonia must be allowed to evaporate *completely* before the copies are stored away.

4. The diazo compound *A* and the coupler *C* are coated on paper after one of them has been changed into an addition compound not susceptible to coupling. Development is effected by decomposition of the addition compound by treatment with water vapour, ammonia or alkaline solution (A. Feer, 1889; F. van der Grinten, 1926).

5. The diazo compound *A* is decomposed by light and a substance *D* is formed which is capable of coupling with the unchanged substance *A*, either spontaneously after a comparatively long time, or immediately by treatment with an alkali. This gives positive prints from negatives. (M. Andresen, 1895; G. Koegel, 1921.)

840. Other Processes. Many other processes producing images in pigment or dye cannot be described here, even briefly. Mention should, however, be made of various processes based on the differential reactions of ferrous and ferric salts with organic colloids, and also the processes based on the tanning of the gelatine of a gelatine-bromide emulsion by the oxidation products of the developer (in particular pyrogallol). Development is carried out in a developer without sulphite or containing only very little sulphite to produce the tanning. Similarly, the reaction products of development may be made to react with amines or phenols added to the developer to form insoluble dyes (R. Fischer, 1912). For instance, violet tones would be obtained by dissolving thymol in a paraphenylenediamine developer. There are also various processes based on the fact that a solution of hydrogen peroxide, acting under suitable conditions on a negative or on a gelatine-bromide positive, dissolves the gelatine in the parts where there is a silver deposit (M. Andresen, 1898).

CHAPTER XLVI

PIGMENT PRINTS FROM SILVER PRINTS

841. General. An image on bromide or chloride paper, can be used to render insoluble either the gelatine enveloping it or another film of gelatine in contact with it. This is done by the action of a substance which converts the silver of the image into a salt, is itself reduced, and in turn reduces a bichromate contained in the gelatine.

If it is proposed to make the gelatine enveloping the silver insoluble, the intermediate reduction product must be insoluble; so that all the reactions take place in these parts. If, on the other hand, a film of gelatine placed in contact with the silver image is to be rendered insoluble, the intermediate reduction product must be soluble, the conditions being regulated in such a way that the final reaction is not instantaneous. The soluble products diffuse into the film to be rendered insoluble.

Of the very numerous applications of this principle we shall describe only two processes in current use in photographic practice. By variation of details of the methods, however, it is possible to obtain images by dusting-on or by absorption of dyes. Prints may be produced by transfer of absorbed dye to another film of gelatine.

A distinct advantage of these processes over those utilizing the tanning of bichromated gelatine by the direct action of light is the considerable reduction in time of exposure to light. As a result, enlarged images may be made when required.

THE CARBRO PROCESS

842. Working Methods. In the Carbro or Ozobrome process, invented in 1906 by T. Manly and improved by H. F. Farmer, in 1919, a carbon print is obtained from a bromide print, by single transfer, without lateral reversal of the original bromide print. The result is as good as a direct carbon print in all cases where critical sharpness is not required. After rinsing and re-developing the original image can be used again for making further carbon prints, up to a maximum of about ten copies.

The bromide print should be made on a paper with very hard gelatine. The most suitable paper is a smooth mat bromide paper

without supercoat. Papers specially recommended for the process are available commercially. Development should be carried as far as it will go. Fix in two baths, and wash very carefully.

The carbon pigment paper is cut to such a size that it projects at least a quarter of an inch beyond the bromide print on all sides and is immersed for three minutes in Bath No. 1 below (F. R. Newens, 1930)—

Stock Solution No. 1

Potassium bromide . . .	100 g
Potassium ferricyanide . . .	100 g
Water to make . . .	1000 ml

Bath No. 1 ready for use

Stock solution No. 1 . . .	20 ml
Water . . .	80 ml

The paper is taken from Bath No. 1 and squeegeed, gelatine side downwards, on to a sheet of glass and blotted off. It is then stripped from the glass and placed in the second bath where it remains from 15 to 40 seconds. The shorter the time of immersion in this bath, the more contrasty the print will be.

Stock Solution No. 2

Potassium bichromate . . .	40 g
Chromic acid . . .	40 g
Chrome-alum . . .	100 g
Boiled water to make . . .	1000 ml

Bath No. 2 ready for use

Stock solution No. 2 . . .	20 ml
Boiled water . . .	80 ml

Bath No. 1 can be used repeatedly, provided it is occasionally filtered. Bath No. 2, which is subject to continuous alteration by additions from the first bath, must be renewed frequently, at least once during each spell of print-making. For the use of the Carbro technique for three-colour prints a fresh bath for each pigment paper is to be preferred. This technique is fully dealt with in Chapter LIII.

In the meantime, the bromide print, previously soaked in water until the gelatine is completely swollen, is placed face upwards on a sheet of glass.

The carbon pigment paper, on removal from

bath No. 2, is laid with its gelatine surface against the silver image, leaving a uniform margin all round. Excess of liquid is rapidly removed with a squeegee, avoiding any shift between the two surfaces which may give rise to double images. The two papers are removed together from the glass, and left for a quarter of an hour between sheets of waxed paper. During this time, a sheet of single transfer paper, cut a little larger than the carbon pigment paper, is immersed in water for three to five minutes according to its thickness. It is then placed on a sheet of glass, gelatine-coated face upwards. The bromide print, now bleached, is gently separated from the carbon tissue, and placed in water. The carbon tissue is applied to the transfer paper and squeegeed down firmly. The sandwich is left under pressure between damp blotting-paper for about 20 minutes. The papers are then removed from the blotting paper and slid into a dish of water at a temperature of between 90° and 95°F. When pigmented gelatine begins to ooze out at the edges, the backing paper may be gently peeled off, and the remaining soluble gelatine washed away.

The bromide print is washed in several changes of water, for at least 20 minutes, before being fully re-developed in white light. The re-developed image is then washed without fixing.

Various formulae have been published for replacing the two successive sensitizing baths by a single bath. However, single baths do not allow so much control of contrast, and the prints successively obtained from the same silver image become more and more contrasty. The density of the shadows increases whilst the details in the high-lights progressively disappear. Where only one print is required, the single-bath technique has the advantage of being easier to standardize. For this reason it is often used in trichrome carbro printing (Chapter LIII).

843. Theory of the Carbro Process. The potassium ferrocyanide formed during the action of the mixture of potassium ferricyanide and potassium bromide on the silver constituting the original image reacts slowly with the bichromate, reducing it to chromic compounds which tan the gelatine, whilst the ferrocyanide reverts to ferricyanide. A small fraction of the silver is attacked directly by the bichromate after immersion in the acid bath, but the chromic compounds arising from this secondary reaction tan the gelatine of the bromide paper

in situ, and cannot contribute to the formation of the final image. The fact that this reaction removes a certain fraction of the silver from participation in the main reaction explains the reduction of the contrast of the final image when immersion in the acid bath is prolonged.

The beneficial effect of the acid on the preservation of the high-light gradation appears to be as follows (F. J. Tritton, 1926). The hard gelatine of the bromide print has swollen to the maximum possible extent during its long immersion in water before being placed in contact with the carbon pigment paper. The soft gelatine of the carbon paper, on the other hand, which has been immersed for a short time only in a neutral bath, and then, at the last moment, in an acid bath which favours swelling, does not have time to swell much. Swelling therefore continues after it has been applied to the silver image, at the expense of the water contained by the bromide paper. The water is thus attracted, by a kind of suction, towards the layer of coloured gelatine. In this way, the diffusion of the potassium ferrocyanide formed in contact with the silver is directed towards the carbon pigment paper in a direction normal to the surface of contact. This is the reason why there is no appreciable loss of sharpness, as would be the case if the diffusion were not directional. It has been found that the images are much less vigorous and sharp if the bromide paper is only slightly swollen and the carbon pigment paper is fully swollen at the moment of placing them in contact.

By producing a very slight superficial tanning, the formaldehyde facilitates the tanning of the gelatine by the very small quantities of chromic tanning agents produced in the high-light details of the image. Finally, the acetic acid present in some formulae allows the gelatine to swell without promoting unduly the direct action of chromic acid on the silver, as hydrochloric acid does.

THE BROMOIL PROCESS

844. The Bromide Print. The conversion of a bromide print into an image in greasy inks was described by E. J. Wall and C. Welborne Piper in 1907.

The bromide papers prepared specially for this process have a thick layer of emulsion, made with a very soft gelatine. Beginners should use one of these special papers which are available commercially but ordinary bromide papers can be used, provided those with gelatine

which give good relief on swelling are chosen. It is well to choose mat papers on a stout, smooth base, with a coating able to stand transfers. Mat papers, as a rule, do not have the supercoat of gelatine used on the emulsion of glossy papers to protect it from abrasion. Moreover, mat emulsions contain starch grains, which do not swell so much as the gelatine on wetting, and thus produce a granulation of the surface of the gelatine which greatly facilitates inking.

The lightest tones of an ordinary image on bromide paper are not usually recorded in the final inked image, whereas the heavy tones are accentuated. The working conditions must be adjusted, therefore, so that the tones of the silver image range from a clear grey to a deep grey, and not from white to black. To obtain such an image, of sufficient depth and with only slight contrasts, ample exposure must be given with short development. Fog must be avoided, as this would reduce the swelling.

For the same reason, old developer should not be used, since the oxidation products of development may cause a slight general tanning of the gelatine. If a tanning developer (e.g. pyrogallol) is used, the quantity of sulphite needs to be increased in order to confine the hardening action to the gelatine of the image.

In order to allow the maximum swelling of the gelatine after wetting and before inking, the silver forming the image should extend, at any rate in the blacks, throughout the whole depth of the emulsion. In order to achieve this it is desirable to expose the paper fully and to develop the image for a short time in a slow-working developer. Acid amidol developer is favoured for this purpose by some workers.

Fixing can be done in a bath acidified with sodium metabisulphite. The fixing bath must on no account contain alum, which would reduce the swelling of the gelatine.

845. Bleaching the Image. Various methods have been proposed to ensure the tanning of the gelatine at the points where it encloses the silver of the image, in the course of which the image is bleached by conversion of the metallic silver into silver bromide. However, all of these methods give practically the same results.

Bleaching may be done as soon as the print has been washed free from hypo; or it may be done after drying, in which case the operation may be postponed to any convenient time. Excellent results have been obtained on bromide prints several years old.

It is usual to use a bath containing cupric bromide, or an equivalent mixture of potassium bromide and copper sulphate and a bichromate or chromic acid. The substitution of sodium chloride for potassium bromide only slightly modifies the results (H. D. Murray and D. A. Spencer, 1933). The use of an acid bath, sometimes recommended for bleaching prints with excessive contrasts, tends to induce a general tanning of the gelatine; subsequent swelling, and, therefore, inking, is then much more difficult. The most that should be done is to add a trace of acid to a very hard water in order to neutralize it, but it would be better to use boiled water. The following bath may be recommended. Sufficient solution for one print should be mixed just before use and should be discarded after use.

10% solution copper sulphate	250 ml
10% solution potassium bromide	500 ml
1% solution potassium bichromate	100 ml
Water to make	1000 ml

In this bath the image gradually weakens, and in a few minutes disappears almost completely. The print is left in the bath until bleaching is complete. In any case it should be left for at least four minutes to avoid unevenness. If bleaching takes more than five minutes the bath is probably exhausted and should be replaced by a fresh one.

When treating a large number of prints, the bleaching of the image and the tanning of the gelatine may be done in separate operations by successive immersion in the two baths (H. J. P. Venn, 1926) given below, which keep indefinitely and which may be used many times, even at long intervals.

A	10% solution of copper sulphate	19 parts
	10% solution of potassium bromide	1 part
B	10% solution potassium bromide	2 parts
	1% solution potassium bichromate	1 part
	Water to make	10 parts

The bleached print is washed in several changes of water until the water is no longer coloured. It is then placed in a bath of 1 per cent sulphuric acid in which the last traces of the image disappear, the only sign left being a slight relief of the high-lights. A more concentrated sulphuric acid bath weakens the tanning of the gelatine, especially in the high-lights. Hydrochloric acid has a similar effect. Finally the print is again washed in several changes of water.

The print contains the whole of the silver

which formed the original image in the form of silver bromide which will darken on prolonged exposure to light. This would produce a double tone in the inked image. It is, therefore, best to dissolve this silver bromide in a fresh non-hardening fixing bath. After the usual washing, the print should be put to dry. This drying renders the gelatine in a suitable condition for inking.

846. Swelling of the Image. Inking must be preceded by a swelling of the gelatine, causing the image to appear in slight relief. The best results are generally obtained with the maximum degree of relief. For a long time it was believed that inking up could not be effected satisfactorily except on very much swollen gelatine with a marked relief. Some bromide papers specially prepared for bromoil work ink up perfectly after a very short soak in tepid water which does not produce much swelling, and the image is visible only through the contrast between the mat portions (shadows), and the glossy portions (high-lights). The process can be carried out equally well on a print which has just been bleached, washed, and dried, or on an old print, even one several years old.

To ensure the proper degree of swelling, it is usually sufficient to leave the print in cold water for several hours, or in tepid water (80°F to 95°F) for a quarter to half an hour. It is also possible to hasten the swelling with a solution of ammonia (4 per cent to 10 per cent of ammonia). The print should be rinsed afterwards in cold water.

847. Inking, Finishing, and Transfer. The inking of Bromoils is done in the same way as for oil prints, but usually a slightly softer ink is used.

Inking is rendered more difficult if development of the bromide print has been forced.

On the other hand, if development is incomplete, the gradation will be poor.

As already noted prints may be de-greased or used for transfer. Prints intended for transfer should be laterally reversed in printing.

It is possible to dissolve the gelatine in the lighter tones of a bromoil print by treating it with a very dilute solution of sodium hypochlorite (G. Underberg, 1925). This process inevitably causes a certain loss of detail in the high-lights.

Mention may be made of the possibility of transferring ink impressions in succession on to the same sheet of paper. The same bromide print may be used, or several prints from the same negative, and the inks may differ only slightly in colour, but be of varying consistencies, for double-tone effects. On the other hand, they may be of different colours for multicolour effects. Such effects are acceptable only when really well executed and it is therefore necessary to be sure of one's ability before attempting such work.

A variant of the conventional bromoil method was patented by F. F. Renwick and F. J. Shepherd (1932). This involves the use of a bromide paper with an emulsion hardened during manufacture. Development is stopped in a weak acid bath (borax and boric acid) and the bleaching bath is kept at the same acidity. This avoids the difficulties which often arise owing to a local accumulation of calcium salts during intermediate drying. Fixing is done once only, after bleaching, and is followed by washing and drying. The ink is applied with a roller, either to a dry print or to a print swollen with water containing glycerine. The excess of ink is removed under water by means of a felt roller covered with rubber. If necessary, final touches are given by inking with a brush.

CHAPTER XLVII

FINISHING AND WORKING-UP PRINTS: TRIMMING, MOUNTING, RETOUCHING AND COLOURING

848. General. Trimming must obviously remove the edges of the print, which are often defective, owing to gelatine having separated, finger marks, etc. It gives the print a neat appearance, and should also remove unnecessary portions which are without interest or disturb the unity and balance of the composition. It is very rare that the arrangement of the picture on the plate is perfect and that the standard sizes of the sensitive materials, negative or positive, include the subject to the best advantage. There are few photographs but will benefit by judicious trimming.

The purpose of mounting is not merely to protect the print from the friction and wear to which a thin paper is exposed; it aims also at setting the print apart from its surroundings, so that a spectator can concentrate his attention on it. "The object of a frame is to place round the work an area of restful lines, in quiet tones, which isolate it from the coloured confusion of the walls; the prime quality of a frame is unobtrusiveness" (C. Puyo, 1903).

Neither the paper nor the card which forms the background, nor the frame, can greatly improve a photograph, but it is equally true that they can, when badly chosen, do it a great amount of harm. The mounting of a print should therefore be studied, from the point of view of avoiding a commonplace and also an extravagant effect.

849. How Much to Trim. The amount of picture to be trimmed away is best found by trial, using two L-shaped pieces cut out of thick paper and marked with a scale of half-inches, the numbers starting from the angle, so as to be sure of forming a rectangle. This preliminary study of the picture may result in sacrificing a relatively large portion of it. It is, therefore, well to carry out this trimming as soon as the first print has been made from the whole of a negative, for in this way it may be seen at once whether or not a smaller portion may give a better composition.

In doing this, the general rules of artistic composition should be followed, and attention paid to the following points.

In the case of a profile or three-quarter-length

portrait the head should not be centred on the vertical axis of the trimmed print; more space should be left on the side towards which the model is looking. In the case of half-length or full-length portraits, the trimming will have a great effect on the apparent height of the sitter, who is dwarfed if the photograph is trimmed at a point far above the head (this is the usual way of trimming children's portraits). On the other hand, the height of a figure appears greater if the print is trimmed close above the head.

In photographs of architecture, landscapes with monuments, or industrial subjects, the trimming of the print should depend entirely on the vertical lines of the subject. Never depend on the horizontal lines, which, one knows, are not generally parallel with the horizon. If the picture has not been properly registered on a vertical plate, and if, consequently, the images of the various vertical lines cannot be parallel to each other (§ 34), choose judiciously an average vertical line, so as to distribute the error; trimming in parallelism with one of the vertical lines nearest to one of the sides will give the verticals on the other side an exaggerated obliquity.

Landscape often includes no vertical lines at all. In this case one is guided preferably by water (the apparent horizon of a seascape or a panorama, lakes and rivers), or by the average perpendicularity of trees. Failing such indications, trimming is done so as to render the perspective of the picture to the best advantage.

Having decided where to trim, mark the lines on the print with a hard, finely-pointed pencil, or, at least, mark the corners of the rectangle which the trimmed print is to form. For paintings and drawings artists have adopted rectangles, the proportions of which are not simple whole numbers. A rectangle is often considered ideal when its sides are in the ratio of $(\sqrt{5} - 1) : 2$. This is sometimes known as the "golden mean."

For the sake of variety in a collection, or to cut out part of a defective print, photographs are sometimes trimmed to circles or ovals (ellipses). Such fancy trimming, however, should

be used with restraint. A profile head may suitably be trimmed to a circle, after the manner of a medallion, or a half-length portrait may be cut to an oval.

850. Trimming. The trimming of prints is usually done with a shearing blade or cutter, operated by hand or foot. The usual pattern is one in which the cutting blade is fixed to a base on pivots which allow it to swing to and fro slightly. The print is placed on a bed which butts against the blade by the operation of a spring. On the bed being pressed down against the cutting edge of the blade, any margin of print projecting from the bed is cut cleanly off. Those models are to be preferred which comprise a squared guide or a bed ruled in squares, the object, in either case, being to ensure rectangular corners when trimming. With some trimmers, specially designed for trimming prints with a narrow white margin, there is an adjustable arrangement ensuring automatically that each cut is made at a constant distance from the (masked) edge of the picture, this distance having previously been set by a register stop. The alternative means is to use a cutting tool, guided by a rule or set-square of glass or steel. Bevelled rules or set-squares should not be used as the cutting tool is liable to slip to the fingers holding the instrument down on the paper. Trimming with scissors demands great steadiness of hand and eye, and is rarely done.

A suitable tool is either a bookbinder's knife, fixed in a handle with a tightening screw, or a penknife, or a vaccination lancet in the form of a pen mounted in a stout penholder. Whatever may be the tool chosen, it should be frequently sharpened on an oilstone.

The transparency of trimming shapes and set-squares of polished glass is an advantage, but there is always a risk of their slipping over the print during cutting. Moreover, there is no need to see the picture if the cutting line has been determined beforehand. Ground-glass set-squares, which are sometimes used, have no advantages over those of steel. In order to prevent steel rules and set-squares from slipping over the print it is a good plan to stick on the underside a strip of ordinary thin adhesive fabric-tape which must, however, be kept clean. Rules and set-squares made of wood or ebonite should not be employed; they are liable to get chipped and so be rendered useless.

For trimming, the print should lie on a flat bed, soft enough to avoid the necessity for

frequent sharpening of the tool. The best cutting beds are those of wood, made with the surface at right angles to the grain of the wood, as is done in the case of butchers' blocks; cuts made by the trimming knife thus disappear on wetting with water. Sheets of roofing zinc are often used (if new, they should be roughened to prevent slipping). The disadvantage of glass is that it very quickly blunts the tools. Again, the bed may be a sheet of cardboard or a pile of sheets of waste paper.

Prints may be trimmed wet, using glass shapes and a wheel cutter, laying the prints face down on the glass.

Trimming with deckled edges is sometimes adopted for prints with wide margins on coarse-grained cards, and obviates the necessity of mounting on cardboard.

Photographs printed in large numbers are, preferably, cut up in piles on a guillotine. For this it is necessary that the various sheets are piled in such a way that the pictures are exactly superposed, either by bringing two sides of each sensitive sheet against fixed studs when printing them, or by punches on the bed of the printer by which each sheet is perforated, these perforations allowing of the finished prints being registered on the bed of the cutting machine.

851. Choice of Mounts. In choosing mounts for prints there are various points to be considered.

In mounting silver prints with paste, it is very important that the mounting board should be free from sodium thiosulphate which is used in the manufacture of paper to destroy any excess of the hypochlorites used to bleach the pulp. This is liable to spread into the print before the paste is dry, and to affect the image in time. In the same connexion, the use of cards with bronzed (imitation gold) lettering should be avoided; the print may be defaced by particles of metal adhering to the card.

• Cards used in wet mounting should be capable of resisting the tendency to curl as the print dries.

When the prints are to be framed "solid" or "close-up" in wood frames (the mount not showing between the picture and the frame), the colour of the mount is of no consequence, but in all other cases the texture and the colour of the mount must be considered. From this point of view, very useful information may be gained from a careful study of engravings, charcoal drawings, red crayon drawings, and other works of art in monochrome in museums, exhibitions, and in the windows of picture-framers. In a

matter where taste and personal preference play the chief parts, it is obviously impossible to lay down hard and fast rules, but a few hints may be given with advantage.

The mount should never be glossy or of bright colour. It must be remembered that a dark mount makes the lights of the picture look lighter, and, conversely, that a very light-coloured mount will increase the apparent depth of the blacks. The tones of the picture in relation to the mount may be made effective either by harmony or contrast, but colour contrasts are to be avoided if the picture is not in itself of considerable vigour. Blue tones (and blue-blacks), as well as browns, lend themselves generally best to an harmonious combination with the mount; red and reddish tones will stand either harmony or contrast (for example, yellowish, greenish, or grey-blue mounts); pure black tones suit mounts of almost all shades. When there is any doubt, a neutral grey should be chosen; this tone suits any colour of the picture. It is often sufficient to have a narrow border, separating the picture from the mount, in order to modify their mutual effect.

Fortunately, the use of variegated and ornamental mounts, always in bad taste, has been abandoned. Dry-mounting methods, allowing the use of thin mounts, have provided photographers with mat or rough papers of the many shades used for magazine covers and in modern high-class printing, in addition to drawing papers. Commercial nomenclature for the sizes of these papers is as follows—

Medium	18 in. × 23 in.
Royal	20½ in. × 25½ in.
Double crown	20½ in. × 30½ in.
Demy	17½ in. × 22½ in.
Double cap	17 in. × 27 in.
Large post	16½ in. × 21 in.
Imperial	22 in. × 30 in.

When not used alone, such papers may be pasted to the cardboard (e.g. with starch paste) under suitable pressure. It is also possible to use fabrics pasted on card or, in the same conditions, leaves of wood veneers: rosewood, olive, walnut, etc.

Thin papers, especially in dry mounting, may be used with very pleasing results in *multiple mounting*. By backing the print with a series of progressively larger mounting papers of varying size and tone a series of borders is produced. The result is similar in effect to that obtained with wash and line on the cut-out mount used for framing engravings and water-

colour drawings. A warning may be given against allowing the different borders to follow each other in order of depth of tone.

Interesting effects may be obtained on light, smooth mounts by a toned border applied by means of an air brush (§ 866), as follows. The print is laid flat on a table and covered with a rectangle of stiff paper (trimmed with the print) covering the picture exactly, and is held in place by a strong glass plate (window glass or trimming shape), forming a paper weight. A rectangular mask cut out of stiff paper is centred exactly round the picture so as to expose only the part to be tinted; this mask is held in place by four strips of strong glass, placed very near the edges (the same set of four strips suits very varying sizes if suitably placed). Then a very light tint of grey or bistre is laid on. If desired, this border may be completed by a border-line done with the drawing-pen in the same colour but a deeper tone. It is well to protect the mount from any contact with the steel rule (used for the lines) by covering each time with a piece of white paper the portion under the rule. The masks and counter-masks should be kept in proper order near the work table.

Before deciding on a mount, the print should be placed in conjunction with papers of different tints, more or less deep, so as to find the one that shows the picture to the best advantage. In choosing colours, beware of those which show differently in more or less yellow artificial light.

For attaching prints without the use of an adhesive, gummed fasteners are sometimes fixed to the mount; they have slits into which the corners of the print are slipped. This method is of more general use to amateur photographers for mounting small prints in albums. Finally may be mentioned the use, as mounts, of panels of veneer wood (for pictures of very large size), or of stout canvas (photographs used by commercial travellers).

The albums sold for collections of photographs are very frequently unsuitable for individual requirements. In such a case one may make an album for oneself by taking the sheets on which the prints have been mounted to a bookbinder; or, simpler still, the various sheets may be united by a cord, and a cover may be made of two pieces of cardboard (covered with paper or fabric), piercing in each two holes by means of a punch. In this case the punch must be fixed to a board on which have been screwed wooden blocks, forming stops, so that the perforations

may be always made in the same places. As regards albums bought ready-made, choose those with removable leaves, which give the collector more liberty in mounting his prints.

852. Placing the Picture on the Mount. A picture placed precisely in the centre of a mount will always appear to be too low. It is a tradition almost universally accepted that if the greater dimension of the mount is the vertical one, the upper and the side margins should be the same width, and distinctly narrower than the depth of mount below the print. If, on the contrary, the larger dimension of the mount is horizontal, the lower margin and the side margins should be equal to each other, and the space above the print of distinctly less depth. This rule applies even in the case—which is rather exceptional but sometimes quite good—of a picture mounted lengthwise on an "upright" mount. The depth of the lower margin should differ very little from the height of the picture itself.

Lateral centring of the print is facilitated by the use of a divided rule with the zero in the middle, the two sides being numbered symmetrically (V. Jobling, 1910). It is sufficient to cover the numbering on a 12-in. rule with a band of paper, and to mark the new scale on this band.

As a general rule, the margins are relatively much larger for a small print than for one of very large size.

In multiple mounting, use is made alternately of bands of very unequal width, some being so narrow as to be merely lines. For example, the picture may be separated from the outer border (which is always the largest) by a line and band, or a line between two bands, or a band between two lines. Trials may be easily made on one of the corners of the picture, the successive mounts being applied so as to show the final appearance along two sides only of the picture. The under-tints frequently harmonize best by resemblance one to another when at least $\frac{1}{4}$ in. wide; narrow edges usually harmonize best when they contrast with the average depth of the picture and the colour of the mount.

853. Various Methods of Fixing the Print on the Mount. For many years the fixing of photographs on to their mounts was done with starch paste or, sometimes, gum arabic. The inconvenience of this method is that the print expands before being applied to its mount by the moisture of the paste, and thus becomes distorted in shape, since the expansion takes place entirely at right angles to the fibres of the paper (§ 677),

and persists after drying. Moreover, the strain put upon the card by the print tends to curve the whole, the print then appearing on a concave mount, unless steps are taken to prevent this curling or to remedy it.

For mounting glazed photographs (§ 764) a narrow edging of rubber solution may be applied to the print, there being then no moisture to impair the brilliancy of the surface.

Red or yellow spots which are sometimes noticed on prints mounted with rubber solution are due to the action of the solvents on the dyes in the mount.

In course of time, dry-mounting has come into common use. The usual "tissue" is thin paper ("onion skin" or foreign post paper), impregnated on both surfaces with a preparation of shellac or thermo-plastic resin.

The sheet is placed between the print and the mount. In either case, pressure of the whole at a sufficiently high temperature melts the shellac, thus ensuring perfect adherence of the print, without distortion of the image or curling of the mount, and with the additional advantage that the print is isolated from the mount and its possible impurities by an impervious coating; also the print may at any time be detached by subjecting it to a temperature slightly higher than that used for mounting.

More recently it has been the custom to attach prints on their mounts only by the upper edge, which gives the print no protection at all against being rubbed or torn. When this method of mounting is adopted by professional photographers it is customary to use a mount whose horizontal dimension is twice the ordinary width, and which is folded over on the print (*folder mount*) so as to provide it with a protecting wrapper.

854. Mountants. Adhesives for mounting photographs must not contain either acid (found in many liquid office pastes), which would cause the print to deteriorate or alter its colour, nor hygroscopic substances (e.g. glycerine), which, by keeping the print slightly damp, renders it liable to be affected by the atmosphere.

These conditions are fulfilled by freshly-prepared starch paste, which is specially suitable for thin papers, and by dextrine, which is thicker and more adhesive, for use with thick papers.

In exceptional cases use is made of a solution of gum arabic, or of strong liquid glue (the kind usually sold in tubes for domestic purposes), or of rubber solution.

To prepare starch paste, about 100 g of rice starch are mixed with 100 ml of water (preferably in a mortar), making a thick cream, without lumps. This is poured slowly into about 250 ml of boiling water, which is kept boiling while the mixture is stirred with a spatula or wooden spoon until it turns to a bluish translucent liquid, which thickens on cooling. The adhesive power of the starch can be greatly increased by dissolving in it, while still hot, about 3 to 4 g of gelatine, previously well swelled in cold water. Whilst the mixture is still warm about 0.2 g of salicylic acid or of thymol may be added to it, to retard slightly the spontaneous liquefaction (due to bacteria), which, otherwise, begins in a few hours. The paste should be filtered while warm through a piece of fine linen, so as to remove lumps and any extraneous matter. It is also possible to use the soluble starches such as are supplied for pasting wallpaper. The paste is made by mixing the dry powder with a little cold water, and it keeps very well if an antiseptic, especially a very small amount of formalin, is added to the water.

Dextrine paste is a thick, white, opaque mountant, which keeps indefinitely and is much used in offices. It is made by bringing about 1,000 ml of water to a temperature of about 176°F (this temperature should be maintained throughout the operation); in this is mixed 500–600 g of white dextrine, adding a little at a time, and maintaining the temperature until a translucent liquid is obtained; to this is added about 1 g of thymol. It is filtered through fine linen and put into pots, closed at first only by a piece of linen. At the end of a few days the mixture becomes a thick paste; the pots may then be corked. For use, the paste is thinned with a very little water, about as much as the brush will hold.

Solution of gum arabic is prepared with the pale gum, roughly broken up and hung in a small muslin bag, in its own weight of warm water, with the addition of about 0.1 per cent of thymol. When completely dissolved it may be filtered if necessary.

855. Full Mounting. Mounting is done with a fairly stiff hog-hair brush, of the flat, "fish-tail" type. The brush, once charged with the necessary amount of mountant, should not be put back into the paste, nor should it be left so that the hairs pick up dust or soil the work table. In the handle, as near as possible to the metal binding, may be screwed small wooden pegs, the end of the handle being weighted with lead,

so that, when the brush is laid down, the hairs are kept out of contact with anything.

The prints to be mounted are soaked for a few seconds in water, and piled face downwards on a sheet of glass (obviously this method is not suitable for glazed prints, which must be mounted dry by means of an edging of stiff mountant). The top print is then coated with mountant. The print is then lifted off and at once laid in its place on the mount; it is then covered with a piece of hard paper, and contact is ensured by pressure from the centre outwards with a linen pad or a rubber roller squeegee.

To ensure correct placing of the print on the mount, the latter may be covered by a mask which is slightly larger than the print, and is held in position by weights; or the print may be laid face down on a card the same size as the mount, and centred correctly on it. The mount is then pressed down on the print, its edges coinciding with those of the card.

If the mount is not liable to be injured by moisture, the print may be pressed into place with a damp sponge, at the same time removing any mountant from the edges.

To keep the mount flat during the drying of the print, the mounted photographs are piled, face down (placing the first on a piece of blotting-paper or very clean ordinary paper), with a weight on top. Also, while drying, they may be curved in the opposite direction by slightly springing them between pairs of wooden strips nailed to a board, the distance between the strips being a little less than the width or height of the cards. Also, if the cards on which prints are mounted are not stained by water, the place on the card where the print is to be applied may be moistened with a wet sponge, mounting being done when the card is bent.

For mounting on canvas, the canvas should first be stretched on a stretcher frame (similar to those used for oil paintings). The print is laid face down on a glass slab and mountant applied to the back. The canvas is then laid on, firm contact ensured, the glass removed, and the print and canvas are left to dry, the canvas not being taken off the frame until completely dry.

856. Dry-mounting. Dry-mounting, by means of adhesives with a shellac base, is suitable for all papers the gelatine coating of which has been hardened by alum, provided both print and mount are perfectly dry. In the case of rough papers, however, there is a risk of the grain being somewhat crushed. When

dry-mounting papers with a "velvet" (velours) surface, due to free fibres, these fibres must not be crushed if the image is to retain its characteristic qualities. The face of the print should be protected, during its passage through the press, by a pad of felt covered with thin paper, which will prevent the fibres of the felt being caught up on to the paper fibres. Gum-bichromate prints, even when treated with alum, do not usually stand dry mounting; prints in greasy ink, previously deprived of grease, and also transfer prints (after about eight days) may be dry-mounted without difficulty.

For ordinary work, dry-mounting is done in a press, the upper plate of which may be heated to about 175°F, as indicated by the thermometer. The thermometers fitted on dry-mounting presses should be capable of withstanding a *very much higher* temperature than that normally required, as otherwise they usually burst the first time they are used. Presses of "swan-neck" pattern, which permit of the insertion of prints and mounts of any size, are preferable to presses with two uprights of the copying-press type, permitting the mounting of large prints being done only in several stages. It is convenient to set up the press so that its lower table is prolonged by shelves, fixed or movable, particularly when it is desired to mount prints of large size in several stages. The wheel may be bound with cloth to prevent blisters on the hands.

The vertical slides must be lubricated with a little graphite, greasy substances being avoided on account of the risk of spots. A very little of a grease with a high melting point should be used for the screw and joint. The press should be dismantled from time to time for cleaning. If the press is heated by gas the burners must be cleaned frequently to prevent the orifices being closed and the accumulation of soot.

For occasional work, special irons may be used, similar to laundry irons, heated internally by gas or electricity and fitted with a thermometer; or, again, ordinary flat irons (preferably those termed "glazing irons") may be employed.

Mounting comprises several successive operations: (i) fixing of the adhesive tissue to the print to be mounted; (ii) trimming of these two together; (iii) fixing the adhesive tissue to the mount; and (iv) heating the whole under pressure, in order to unite finally the adhesive to the two surfaces between which it is placed.

Prints to be mounted must be perfectly dry, and the adhesive tissues should be kept from damp.

The attachment of the print to the adhesive tissue is done with an iron resembling a small soldering iron, usually heated in a flame of gas or spirit or electrically. This iron should be perfectly clean. It can be cleaned with fine emery cloth. The print is placed face down on clean blotting paper and an adhesive tissue laid on it. The tissue is then touched at several points, without too much pressure, by the hot iron.

The print and the tissue are usually trimmed at the same time to ensure perfect registration of the corresponding sides, but the cutting tool should, as far as possible, be held a little obliquely, so that the tissue is slightly smaller than the print. With some obliquely cutting trimmers the tissue tends to be a little larger than the print, and there then appears a shining edge of shellac around the mounted print. Some workers prefer to cut print and adhesive separately, making the latter about $\frac{1}{8}$ of an inch smaller than the print; the tissue is then provisionally attached after trimming.

The print and the attached adhesive tissue are placed on the mount, and, slightly raising first one edge of the print and then another, the tissue is fixed firmly to the mount by some touches with the fixing iron.

For the final fixing, the print is placed face up on a wooden slab, or on a zinc sheet, and covered with a thin zinc sheet, polished for glossy prints, and grained for mat prints (when mounting with the flat irons these zinc sheets are sometimes replaced by white paper). Before placing the print between the zinc sheets proof of the absolute cleanliness of the whole should be made by trial on a piece of clean blotting-paper.

The order should be reversed when using a press in which the heated plate is the lower bed.

Dry-mounting may be done on embossed mounts by the insertion of some packing so as to limit the pressure to a point between the surface of the print and that of the mount.

The zinc sheet must be cleaned with methylated spirit to remove traces of the adhesive; it must never be scraped.

The whole is slipped under the hot press at the desired temperature (usually 155°F for all prints on thin paper, 175°F for thick papers), and pressure is maintained for 4-10 seconds according to the thickness of the paper, when the zinc sheets are taken from the press and the print removed.

As soon as a print taken from the press begins

to curl it should be bent in the opposite way while cooling.

857. Preparation of Tissues. Adhesive tissue may be prepared by impregnating very thin, *unsized paper* (letter-copying paper) with a mixture of the two solutions (A) and (B) given below, prepared on a water bath—

A	Methylated spirits	300 ml
	Pale shellac	200 g
B	Methylated spirits	400 ml
	Gum elemi	50 g
	Syrupy Canada balsam	50 g

This mixture may also be used as a coating on the backs of prints (or papers used for multiple mounting), but, in order to prevent the alcoholic solution from going through the paper and causing patches on the face, it is necessary to size the prints fairly strongly with two coatings of starch paste (the second coating not being applied until the first has dried), or by a coating of thin gum-arabic (the perfect continuity of which can be seen by its gloss when viewed very obliquely).

In the case of glazed prints, these various coatings are done before the print is removed from the glass or ferrotype sheet.

858. Failures in Dry-mounting. The chief failures which occur in dry-mounting with adhesive tissue are as follows—

The Print Comes Away, Leaving the Tissue on the Mount. The press was too hot. (This temperature of the press is suitable for removing a dry-mounted print from its mount.)

Print and Adhesive Come Away from the Mount. The press was not hot enough.

Unequal Adherence, in Various Places, of the Print. Unequal pressure or heating.

The Print Sticks to the Zinc in Contact with it. Either the gelatine of the print or the zinc was damp.

A Mat Print Becomes Glossy. The press was too hot, or the print slightly damp; the remedy is to mat the print by friction with a pad of cotton charged with powdered pumice. A print on glossy paper which becomes more glossy in patches (because of unequally distributed moisture) should be waxed.

Patches of Different Colour on Print-out Papers. Use of too hot a fixing iron for attaching the adhesive tissue to the print.

Shiny Edging of Tissue Round the Print. The print was not quite dry before mounting, and

has shrunk on drying in the press; or the tissue has been cut too large; or the print has been kept too long in a press which was too hot, thus causing the resin to flow.

859. Waxing and Varnishing Prints. Silver prints may be very effectively protected against atmospheric action by waxing, the process also enhancing the depth of the blacks on mat paper to an appreciable extent.

The waxing solution may be prepared by melting paraffin-wax on a hot iron, and letting it run into petrol, conducting the operation in a room where there is no fire or naked flame. On cooling, the waxing solution will have the consistency of thick cream. This is spread on the print by circular frictional movements, using a flannel pad.

Another way to give a certain degree of depth to the blacks of mat prints is by treating them (by means of an air-brush or atomizer) with a thin solution of gum arabic, but this gum, unlike the wax, does not afford any protection to the print. Prints may also be varnished uniformly by using a celluloid varnish, sufficiently diluted by the addition of amyl acetate, or butyl acetate, to avoid a glossy coating, even on mat prints.

The suggestion has been made to varnish bromide prints by means of a fatty varnish (medium lithographic varnish, forming the excipient of fatty inks), restricting the varnish to the blacks of the image. For this the bromoil method is used, but varnishing with the brush is done on the image which has been re-developed before swelling.

These various operations should be deferred until after spotting (§ 864) and retouching (§ 865), whenever such work is called for.

Imitation enamels, used especially in inferior jewellery, are made from a photographic print (mounted on card) which is covered with successive layers of a transparent varnish. The colourless cellulose varnishes used in various trades (coachbuilding, the leather trade, etc.) can be advantageously employed. These varnishes must be spread by means of sprayers, similar to the air-brushes used for retouching but larger, and constructed for use with air at higher pressure.

Imitation enamels are sometimes produced by transferring a carbon image on to porcelain, or on to polished opal or enamelled copper. After drying, the print is heated in an oven to 175°F, coated with copal varnish, heated again and the operations of baking and varnishing

repeated until a thick layer of varnish has been built up. The varnish is polished first with finely powdered pumice, then tripoli powder dispersed in oil and finally with levigated chalk.

860. Embossing Prints. At the time when photographic portraits were almost invariably printed on albumen paper and then enamelled, it was usual to *emboss* them (to convex shape) in a special press before attaching them to the mounts. This practice, fortunately, has been abandoned, but another method, almost as objectionable, has been introduced of late years, i.e. plate-marking, as customarily done with copperplate prints made on hand-presses. This practice is, in some measure, justifiable for oil or bromoil transfer prints, which somewhat resemble etchings (the admission committees of some exhibitions are taken in by them!), but there is very little to be said for it in the case of prints obtained by other methods.

Numerous contrivances have been devised for obtaining this plate-mark, either after mounting or even during dry-mounting, e.g. rectangles with sharp or rounded corners, circles, ovals, and their counterparts, in zinc or cardboard. To avoid splitting the paper and gelatine layer whilst embossing the border, the back of the paper can be damped with a mixture of equal parts of water and denatured alcohol, and the plate mark made after drying.

The same result may be obtained, without any special tools, as follows. On an illuminated table (stout ground glass laid on a box containing several electric lamps) is placed a card or mask of outside dimensions equal to those of the plate-mark desired; the cut-out part corresponds with the dimensions of the picture. Owing to the translucency of the support it is easy to register the print correctly on this card. The plate-mark effect is then given by passing a burnishing tool, e.g. the handle of an old tooth-brush, along the card so as to press out the print (or mount) until it touches the supporting surface. In the case of a photograph on an opaque mount the registration of the card is done with the print placed face upwards, afterwards turning over the print and the card on to a sheet of glass or zinc, avoiding any slipping.

861. Outline Photographs on Wood. Full-length photographs, mounted on ply-wood, then cut out and attached to a small wooden base, have met with a certain amount of success of late years under the name of "photographic statuettes."

The prints are secured to the thin ply-wood (about $\frac{1}{8}$ in.) with a strong adhesive, and the cutting-out is done with a fret-saw, following the outlines of the figure. The wood is held obliquely to the plane of the saw, so that the cut makes a slightly acute bevel, the under-surface being thus slightly smaller than the upper. The cut is smoothed with a fine file, the bevelled edge and the back surface are blackened with a mat black varnish, and the cut-out is mounted in a groove cut in a small wood base, which is painted to harmonize with the tone of the print.

862. Combination Photographs. Sometimes it may be necessary to combine different prints, or parts taken from several prints, so as to give the effect of a single photograph. Such is particularly the case with combinations of photographs forming a panorama or with vertical aerial photographs, for making a map which is by no means accurate but is full of detail. The successive parts of a photographic panorama on flat sensitive plates cannot be exactly joined, since a plane perspective does not correspond with a cylindrical perspective (§35). Many makers of panorama photographs, therefore, abandon all attempts at registration, and arrange the successive views (cut to the same dimensions, and made so that two adjoining cuts correspond to the same point on the horizon or on the background) at a fraction of an inch from each other. In this case it is usually preferable that the views appear on a dark ground, which may, in turn, be attached to a lighter mount.

The term *vertical aerial photographs* is used in reference to photographs taken with a camera with vertical axis. Such photographs, if they are taken high enough above level ground, approximate closely to a map. Such is also the case with trick photographs for illustrated papers (heads of known persons substituted for heads of figures taking part in an event, or a scene created by introducing portraits of persons into the photograph of a landscape or building, the respective reproductions being made on scales in accordance with the perspective). These are completed, after combination, by laborious retouching for the purpose of masking the imperfections of the work.

We shall not consider more than the two first cases cited. At the outset, it is to be noted that photographs for combination should always have the same degree of contrast, the same depth, and the same tone. Moreover, in the case of aerial photographs, it is essential that they shall be brought to the same average scale.

The successive parts of a panorama are generally bounded by vertical lines; the various parts of a map mosaic are sometimes limited by a straight edge, which may be placed in any manner, but more often by an irregular line, or by a natural boundary (e.g. fields, roads, railways, etc.). The best position of a division is found by looking through the two prints to be joined, superposing them on a glass brightly lighted from below, protecting oneself by opaque paper from the surrounding light. The quality of the two prints not being always equal in the region common to both, it is well to use as little as possible of the one which is less satisfactory in this respect.

In mounting composite panoramas, the various methods described below may be used.

After the prints have been trimmed along their vertical edges to fit as well as possible, they are placed side by side on an illuminated table or against a window, and register lines drawn from one print on to the other. The prints are then placed in a dish of water, allowed to expand, and then assembled on collodion-coated glass, register marks being correctly aligned. Any required adjustments can be made through the glass. Before the prints are quite dry they are backed with stout paper, wetted until they have expanded to the full, and then mounted with a stiff paste. The contraction of the backing paper in drying counteracts the tendency of the individual prints to separate. After the whole is completely dry, it is detached from the glass, the edges are trimmed, and it is attached to any suitable mount (J. N. Pearce, 1924).

In the case of dry-mounting, the prints, trimmed as above, must first be dried with heat to shrink them as much as possible. They are then mounted on thin paper, previously expanded by moistening in steam. The paper contracts after mounting, and so ensures perfect joins between the prints.

In either case, if it is preferred to allow the prints to overlap each other, the double thicknesses are rendered less conspicuous by dry-mounting the assembled row of prints on a thick but rather soft card, under heavy pressure; in this way the extra thicknesses are forced into the card, the whole becoming more nearly flat.

863. In assembling aerial photographs, the preliminary trials which have to be made in placing them hardly allow of exact joining of prints previously cut to a common boundary. Hence it is necessary to cover a part of each print by the adjacent prints. To avoid extra

thicknesses at the joins, the trimmed prints must be chamfered off so that the thickness at the cut edges of the paper is progressively reduced over a distance of about an eighth of an inch, leaving a layer of emulsion only at the extreme edge. This may be done with glass-paper, after the prints have been trimmed to the required geometrical contours.

Prints are generally mounted on stout drawing paper or linen paper, on which has previously been traced a rough map of the region, drawn to the mean scale of the photographs, this tracing being made by proportional enlargement of the map of the region. Before finally fixing prints in position, trials are made with the prints temporarily placed in position by small lead weights. By raising the edges of those photographs which cover the others, register lines may be traced on the map support, so as to allow of the prints being replaced when they have been coated with mountant. These trials can be shortened, when the photographs have been obtained on successive rectilinear flights, by fixing the prints of each row, by means of a few spots of strong liquid glue (e.g. Seccotine), to two partially stretched elastic bands. It is then easy to adjust the successive rows relative to each other so that the errors are equally distributed between the photographs of each row (B. Melvill Jones, 1925).

864. Spotting. No matter how carefully printing is carried out, it is rare that a few prints do not show minute white spots (shadows of dust on the negative or in the printer) and thus require spotting. All apparent defects in the negative should, of course, have been corrected, the spotting of one negative being obviously quicker than that of a number of prints. When a print is to be mounted, mounting should always be done before spotting and retouching.

Spotting is best done on an inclined easel, fitted with brackets, on which large prints may be rested. Small prints may be held at a convenient height by flat springs fixed to the easel.

Transparent colours should be used for spotting, such as Chinese ink, sepia, Indian red, and indigo; the light tints are obtained by dilution, not by addition of opaque white. Silver images of black tone can be spotted with a solution of naphthalene black. Prints which have been sulphide-toned require a solution of naphthalene brown, adjusted as necessary by the addition of water-colour or dyes. Where prints are to be exposed to the light for long periods, dyes should be avoided because of the risk of fading.

Sometimes a little of the material of the image itself is used, being removed with a little warm water from the trimmed-off edges. It is necessary not only to match the tint and the depth of the adjoining parts of the image, but also to obtain approximately the same degree of gloss. This is done by diluting the colours with water containing a variable proportion of gum arabic solution. The mixture is made on a white porcelain palette, in quantities the size of the head of a pin, a small spot being allowed to dry on a piece of paper the same colour as that of the print in order to judge of its appearance before commencing work. Greatly-diluted colours take badly on gelatine, or are difficult to apply, so that it is best to use the colour almost dry, with a sable-hair brush No. 0 or No. 1, with the point tapered by dragging it along the palette and turning it between the fingers. The spots in the shadows are touched out first, and then, as the brush empties, the lighter parts are treated.

The larger white spots should be touched out, as required, by hatching or stippling with a brush or pencil, endeavouring to produce a texture similar to that of the surrounding image.

Minute black spots are removed with a fine scraper, but not one of those used for negative retouching, as the latter needs much more careful sharpening, and this would have to be repeated after working on paper. After use, wash the brush carefully, dip in it weak gum arabic, shape the point between the fingers, and keep it so that the point retains its shape. The point should not be shaped between the lips; this is dangerous practice as many colours are poisonous.

865. Retouching of Prints. Retouching (or working-up), though exceptional on positive prints printed by contact, is often necessary on prints obtained by enlargement, on account of the magnification of small defects, which are negligible in a direct print, and also for the reason that retouching on the negative then becomes too apparent. Moreover, when there are serious defects in a negative which are difficult to retouch, it is often quicker to do the necessary retouching on an enlargement, from which a copy negative of the same size as the original is then made.

Whilst retouching as practised commercially is carried out chiefly with the air-brush, at least for broad effects, the best retouching is almost always done with the brush and the pencil in dealing with small details, using soft crayon for clouded grounds and areas of any size.

Retouching is best done on an easel, and with a first-rate contact print in view for comparison.

Graphite pencils leave a shiny mark, and are hardly ever suitable except for semi-glossy prints, so that drawing pencils are usually used; these work softly and leave a deep mat black mark. Coloured crayons (sepia, red-chalk) are also used, in addition to white crayons for putting in light accents.

Powder colours, so-called "sauces," are sold in a great variety of hues, especially in tints of black, sepia, red-chalk, and all the usual photographic tones. They may be mixed for production of intermediate colours.

Retouching is generally preceded by treating the print with powdered pumice. The perfectly dry print is placed flat on a table covered with white paper; a little finely-powdered pumice, also absolutely dry, is dusted on the print, and rubbed all over it with a pad of absorbent cotton, using intersecting circular movements, so as to impart a slight bite to the whole surface of the print; the excess of pumice is removed with a soft brush.

With portraits in particular, work is usually begun on the ground, using the soft chalk (sauce). For this, there is required a palette or saucer, a chamois leather stretched on a light piece of wood (the edges being stuck down on the underside), or simply a piece of rather rough cardboard. On it is mixed small pinches of the chalk and pumice powder, the pumice being added in proportion to the lightness of tint required. A little of this mixture is placed on a cotton pad; this is levelled down on a clean place on the palette. The enlargement is placed flat, as for the preliminary friction with the pumice, and the colour spread with overlapping circular movements, beginning in the places which should have the deepest tone, and passing to lighter and still lighter parts, as the pad becomes less charged with colour. The various tones of the background should always be intermediate between the lightest and the deepest tones of the subject proper. Parts on which too much work has been done may be cleared with pure pumice. White accents may be put in with eraser of the kind known as "plastic rubber" (rubber which can be kneaded in the fingers), but the effect is often too rough.

After finishing the ground, the work is continued by first softening crude high-lights, due to reflections and the glaring whites of starched linen, using a leather stump and paper stumps (small stumps of coiled paper), charged with

"sauce," but without pumice. The stump is prepared for use by passing it over the palette from side to side so as to charge it uniformly with colour of the desired depth. Pure whites should be very few in number and small in size. It should be borne in mind that the deepening of a grey causes the adjoining half-tones to appear lighter.

The blacks of the picture may be lightened with a hard eraser (ink eraser impregnated with pumice), cut to a point.

Before any work with a brush is done, any

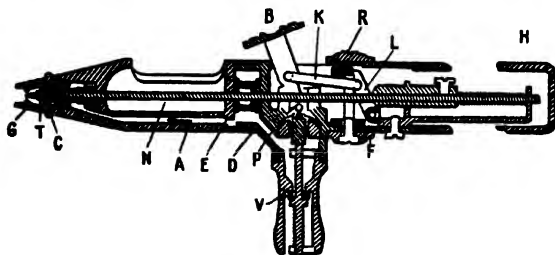


FIG 47.1. MECHANISM OF AN AIR-BRUSH

chalk and pencil work must be "fixed" by steaming, that is, passing the print over a jet of steam from a kettle, so as to soften the gelatine slightly and cause the colour to adhere firmly to it.

It is obvious that the retouching of portrait prints calls for a good knowledge of drawing and the anatomy of the face, subjects that cannot be discussed here.

866. Use of the Air-brush. The air-brush, one of the best models of which is shown in the accompanying illustration (Fig. 47.1), is connected by the lower union (closed, when not in use, by the valve *V*) with a reservoir of compressed air, or with an air compressor. The colour is poured in the cup, through which passes the German silver needle *N*. When the valve *V* is opened by pressure on the button *B*, the compressed air escapes through the passage *A* and the strainer *G*, surrounding the needle with a fine mist through the hollow stem *T*.

The milled ring *R* acts through a slot, limiting the movement of the lever *L*, and, consequently, of the needle *N*, in the direction of its point, so as to obtain a continuous even jet for producing light uniform tints or for drawing lines.

The mechanism of these instruments is very delicate, and one should specially avoid bending the needle. If the latter fails to close the hollow

stem by coming to rest on its conical seat, the jet is caused to splutter. The only dismantling which should be done by the operator is that of the front piece *C*, which should be frequently cleaned.

The colours to be used must be very finely ground and quite free from dust, any particle of grit being liable to be caught in the passages.

To clean the air-brush thoroughly it is only necessary to blow in air under relatively high pressure, after having immersed the whole front half in clean and, preferably, warm water. Then, with one finger, the orifice *G* is alternately closed and opened, expelling the air, by the colour cup and then by the normal orifice.

Pressure for the air-brush is supplied by compressed air, e.g. from a reservoir connected to a compressor which is driven by an electric motor provided with a manometric relay, by which the current is automatically switched on when the pressure falls below a certain value, or switched off when the pressure exceeds a given maximum. Other means are an automatic water-pump, or a reservoir in which pressure is maintained by a pump worked by the foot of the operator.

Use is also occasionally made of cylinders of compressed air, or liquefied carbon dioxide.

The best pressure for the work of retouching ranges, according to the effect desired, from 17 to 27 lb per sq in. (i.e. 4 to 14 lb per sq in. above the atmospheric pressure). Reservoirs connected with the various compressors generally discharge compressed air under constant pressure, controlled as desired by a regulator. We will mention only, by way of example, the method of operation of regulators used on cylinders of carbon dioxide.

Having made certain that the needle valve of the cylinder of carbon dioxide is screwed down, unscrew the hexagonal-headed cap, and adjust the union of the regulator in the thread thus uncovered, interposing a rubber or fibre washer. Close the exit valve (or valves) of the regulator and gently open the needle valve of the cylinder. If the pressure indicated by the gauge is too low, turn the nut (or the key) of the regulator in a clockwise direction; if the pressure is too great, open the exit valve of the regulator, and turn the regulating button the opposite way until the required pressure is obtained. At once shut again the

exit valve of the regulator and, after each time of using, close the needle valve of the cylinder.

867. The colour driven from the point of the air-brush by the jet of gas under pressure forms a conical jet. The farther the instrument is from the paper, the greater is the surface covered by the jet, and the less the intensity of the colour for the same adjustment of the flow. The air-brush can give a flat tint only by overlapping the trails of colour successively deposited on the paper, evenness being the more certainly obtained the larger the number of overlapping bands, and the lower their density.

Just as in water-colour drawing, irregularities are most to be feared at the moment of bringing the brush in contact with the paper and of withdrawing it; so the first and last strokes with the air-brush are the critical moments for the beginner. The hand holding the instrument must already be moving when the finger rests on the button which releases the flow of colour, and its movement should be continued after the spray has been stopped. To obtain a flat tint, it will never do to pass from one band to another without interrupting the flow.

When it is required to obtain a comparatively clean edge, this edge is, in the first place, put on while holding the instrument very close to the paper, so as to trace almost only a line; the air-brush is then drawn farther and farther back according as bands more and more distant from the edge in question are covered.

It is important that the effect of the air pressure be carefully studied, as well as the consistency of the colour and the two movements of the regulating button.

As soon as practice has been obtained in making uniform tints, the next step is the application of overlapping bands parallel to the outline of the drawing.

868. The colours¹ for air-brush work should be kept in closed boxes or in well-corked bottles. It is not necessary to mix the colours beforehand on a palette, the mixture being made and diluted in the cup of the instrument. Whilst in brush-work the depth of the colour should be carefully adjusted beforehand, there is no need at all for such exact regulation in using an air-brush. A colour of full strength permits, if need be, of obtaining of half-tints, but one should avoid resorting to this extreme

measure, a continuous modelling not being obtainable in a light tone by spraying an intense black on a white ground, nor in a half-tone by spraying of white on a black ground.

Moist colours in tubes, and even liquid colours, are to be preferred to colours in cakes, the use of which may cause trouble if there are any badly-ground particles. The homogeneity of the mixture may be secured in the cup by means of a medium-sized hog-hair brush, which serves also to clean the cup.

Since work done with water-colour does not penetrate the gelatine of the image after the manner of inks or of liquid colours, corrections may be made with an indiarubber of medium hardness.

It is always possible to go over a part of the work already done by spraying upon it another colour, either lighter or darker. In fact the capacity of the air-brush in the hands of a skilled worker is exceedingly great.

869. **Retouching of Commercial Photographs for Photo-mechanical Reproduction.** Photographs of commercial articles to be used as originals in the preparation of printing blocks for catalogues are generally worked-up with the air-brush. The retouching is sometimes carried out over the whole image; in fact, partial retouching involves the risk of making the image patchy.

Such retouching is particularly necessary for photographs of machines, on account of the exaggeration in the photograph of the smallest surface defects, stains on the paint, oil marks, etc. Moreover, important details are liable to be lost in shadow; and machines are very frequently situated on a base and against a background not calculated to show them at their best.

The photographic print, about half as large again as the required reproduction, should be printed on glossy or semi-glossy paper, with somewhat exaggerated contrast.

The air-brush alone not being capable of giving perfectly sharp outlines, these latter are obtained by shields or masks, cut from an identical print or from tracing paper, or chosen from an assortment of stencils cut in thin card or celluloid (straight lines, angles of different sizes, ordinary curves, etc.).

For protecting very small areas, use is made of thin varnish (e.g. a solution of colophony in benzene, holding in suspension a coloured powder), which is afterwards removed with a wad of cotton-wool impregnated with benzene, the

¹ When poisonous colours are used, and especially those containing white lead, an efficient system of ventilation must be provided around each work place to prevent the particles being inhaled by the workers.

colour contained in the varnish being removed at the same time.

For prints of black tone it is usual to employ a mixture of ivory black and permanent white; avoid the use of body colour with a white-lead base, which very quickly turns yellow. Certain body whites reproduce as more or less deep greys when photographed on wet collodion with a source of light rich in ultra-violet; some preliminary trials should be made with various brands before finally adopting one (W. J. Smith, 1905).

The colours having been applied, joins require to be made with a brush to remedy the irregularities of outline, or to put in any black or white lines, or high-light accents; further corrections may need to be made with a rubber eraser.

870. Sketch Photographs and Photo-etchings. Under the name of sketch photographs are included portraits on a white background, generally obtained by enlargement on paper with wide margins, in which the photographic image is printed very light and is worked-up by hatching with a pencil (or pen), which tends to give it the appearance of an engraving. This work is usually confined to the shadows on the face, to the clothing, and to the drawing of a background, lightly sketched in afterwards.

So-called "photo-etchings" differ from sketch portraits chiefly in the much greater subjugation of the photographic image, the face itself being completely re-drawn in pencil.

While expert artists may thus produce pleasing results, it is easy, when such work is done without sufficient knowledge of drawing, to get effects greatly inferior to a good direct print worked-up in a straightforward manner.

From a technical point of view, the only item of importance is that of obtaining a pure white ground in the print. This is done at the sitting by specially strong lighting of a uniform white background, slightly inclined towards the light, or afterwards by working-up the negative or by local reduction of the prints.

871. Coloured Photographs. Costume photographs, decorative effects, used for advertisement purposes, as well as certain record photographs (flowers, etc.), are often much more convincing if coloured, even though very slightly. Colouring is generally done with water-colours, using transparent colours, or with dyes. Such colouring requires a light print from a panchromatic negative; a transparent colour obviously cannot show orange or red if applied to black silver deposit in the print.

Apart from this special application, public taste for colour, even in its crudest form, has induced portrait photographers to offer to their customers coloured photographs which, sometimes, are very far removed from works of art. However, specialists in such work may plead extenuating circumstances, e.g. severe competition in prices, or the absence of any data relating to the sitter beyond a mere sketch indicating more or less the colour of hair, eyes, etc. For these descriptions of colouring use is made of pastel and its variants, water-colour (in wash or with an air-brush) and oil-colours. We shall not here consider oil paintings on a photographic base of sensitized painters' canvas, nor miniatures on photographic base, obtained by printing on ivory by the bitumen process of photo-engravers.

As a general rule, colouring must be done in daylight; when work of this kind is done in artificial light it is necessary to use exclusively incandescent lamps in bluish bulbs, affording a light corresponding closely with daylight.

872. Colouring with Dyes. Prints of a purely record character are best printed on glossy paper. Fixing should be done in an acid bath with no alum in it, otherwise the gelatine will refuse to take the colour in places. To facilitate the penetration of the colours, the print, before colouring, may advantageously be immersed for a few minutes in a 1 per cent solution of ammonia, being afterwards rinsed and dried.

For the tinting, solutions of acid dyes in water are used (§§ 754 and 755), a suitable strength being found by trials on waste prints. The colours are applied with a brush, preferably on the dry print, except for flat tints, which may be done after damping the gelatine slightly, but it is then necessary to work very quickly, with the brush lightly charged, in order to avoid spreading the colour where it is not wanted.

From dealers supplying amateur photographers' materials one can get colouring outfits, which usually include four bottles. One of these contains a 2 per cent solution of albumen, with the addition of a small quantity of ammonia and an antiseptic. This liquid is first of all applied "neat" all over the print. It is also used for diluting the coloured liquids before they are spread over the paper. The colouring liquids are aqueous solutions of acid dyes, e.g. naphthol yellow, rhodamine S. or erythrosine, and carmine blue, mixtures of which in various proportions give intermediate tints.

If it is desired to glaze the photographs thus coloured, the colours must be fixed in the gelatine, by suitable mordant, to prevent them from spreading in the picture when wetted. This mordanting may be done, after complete drying of the tints, by five minutes' immersion in the following bath—

Sodium tungstate	10 g
Syrupy phosphoric acid	1 ml
Hydrochloric acid, pure, concentrated	4 ml
Water to make	1000 ml

On removal from this solution prints are glazed without intermediate rinsing.

873. Water - colouring. Water-colours are usually employed on mat prints with a white base, lightly printed, and—at least, in the case of portraits—sepia-toned. After drying, the surface of the paper may with advantage be treated with pumice (§ 764). Otherwise, it is often necessary, in order to facilitate the adherence and uniform application of the colours, to treat with artists' ox-gall.

Transparent colours are the best. Work is carried out on a very slightly moistened print, with a relatively large brush, well-charged with colour, or on a dry print by spraying with an air-brush.

Colours which are unduly bright should be avoided, and the whole process should be done straight off, so that the contrasting effects of neighbouring colours may be correctly judged.

874. Pastel Colours. Treatment of the print with pumice does not always ensure perfect adherence of the pastel properly so-called, and expert workers in these colours sometimes adopt the method of coating the print with a thin and warm solution of fish glue. Then, before this coating has dried, powdered pumice is dusted on with a square-mesh sieve (sieve No. 120 or 150). This coating must be perfectly even, but not so thick as to mask details of the image. The print having been dried, any non-adherent pumice is carefully brushed off. The process is unnecessary when colouring is done with soft chalks mixed with powdered pumice (§ 867).

As a rule, soft pastels are used for the background, and semi-hard pastels for the face; the colour, always somewhat opaque, partially covers the image, so that pastel work calls for a more complete knowledge of drawing than water-colouring.

Prints coloured in pastel must be fixed with a fixative varnish applied with an air-brush.

875. Oil-painting and its Variations. The

materials used, according to circumstances, are transparent colours through which the photographic image is visible, or opaque colours, the photographic image then serving merely as a guide to the artist.

We will consider here only work with transparent colours.

The starting-point, as far as possible, is a light print on moderately rough paper. Taking of the colour is often facilitated by coating the gelatine, a few days before applying the colours, with a very thin and even layer of boiled linseed oil. Once the work is begun, it should, preferably, be carried on to a finish without interruption. When drying is complete, some retouching may be done with water-colours, so as to avoid delay due to further drying.

Prints finished in wax colouring are preferred to those in oil colouring for some commercial work, as they dry more quickly and with a less glossy surface. These colours are prepared by crushing the dry colours on the palette in a medium of white wax and resin—

Pure white soap	15 g
Essence of lavender	60 ml
Genuine essence of terebenthine	840 ml
Gum elemi	30 g
Virgin wax	60 g

The soap is dissolved in the essence of lavender, and the jelly thus obtained is diluted with a little of the essence of terebenthine. The remainder of the essence of terebenthine is used to dissolve the gum elemi, this solution being filtered. The wax is melted at as low a temperature as possible, and, after turning off the gas, the melted wax is poured into the gum solution, to which is finally added the soap jelly.

If the surface to be treated is of large size, the colour is applied with a soft linen pad, any over-running of colour being removed with a rag soaked in terebenthine; in the case of fine detail the colouring is done with a brush.

The colouring may also be done with dry colours ground in a resinous medium obtained by dissolving, on a water bath, 5 per cent of boiled linseed oil and 5 per cent of gum dammar in essence of terebenthine (R. Namias, 1922). After drying, the colours thus applied may be removed locally with an indiarubber; the adherence of the colours being very weak, they must be fixed with a fixative varnish applied with an air-brush.

876. The Flexichrome Process. A process which was originally developed by J. Crawford in

the U.S.A. and which is now being marketed in kit form in America (1950) is worthy of note. A print is made from a normal negative, on a material which is capable of forming a relief image, such as that used in the Dye Transfer Process (§ 1024).

After processing, the image is dyed up with a black dye so that it can be seen for working. Since the thickness of the gelatine is proportional to the amount of exposure at any one point, the amount of dye it will hold is in a like proportion and a normal picture in black and white is obtained.

A set of special dyes (acid dyes) in various colours are supplied which can then be applied to the print, where they replace the black. With some artistic ability excellent colour prints can be obtained in this way. These prints are superior to any of the hand colouring methods used up to the present because the maximum depth of colour is never degraded with black silver and the amount of colour that can be applied to a high-light is severely limited by the small amount of gelatine left to absorb it.

The finished print can be stripped from the temporary support on to paper.

877. Framing Photographs. According to circumstances, photographs may be framed close up to the moulding (§ 851), or with a visible mount between the print and the frame. Much use is also made of mounting simply under glass, the print being made with extra wide margins, or mounted on a board much larger than itself. It is then simply secured to glass by means of a backing card and a strip of gummed paper.

Close-up framing simply in wood is specially suitable for silver and carbon prints. Prints of black or red-chalk tone go well in a frame of dull gold or one of pure empire green enriched with a little gold. Prints of less defined colour are more suitably framed in natural or stained wood; only prints in red-chalk are really suited to a white frame.

There is more latitude in the choice of a frame for prints with wide margins or with a large area

of mount round them, but the fact should not be lost sight of that the essential quality of a frame is its unobtrusiveness. A very wide margin usually needs a very narrow frame, whilst a narrow margin often looks better in a relatively wide frame.

It is a good plan to bind up the glass and the print, and also any backing card, with strips of gummed paper, so as to keep out dust and atmospheric contamination liable to affect the print in time or to cause fading of non-permanent photographs. The gummed binding will be hidden by the frame, and need not therefore be perfectly regular.

In *passe-partout* framing, where the moulding is replaced by a paper binding, this paper should be of a tint and texture appropriate to the print and mount, avoiding imitations of costly materials, which are only too often mere parodies of the real thing.

Before finally fixing the whole, the backing card is fitted with rings for hanging, generally by means of lengths of tape passed through a slit in the cardboard, turned down on the inside, and then stuck in place with a piece of stout paper and a touch of adhesive. The rings supplied on a gummed base do not always give sufficient security, especially for prints of large size.

An even width of paper binding on all four sides of the glass front is essential to a good appearance. Use may be made of the gummed papers specially prepared for this purpose with a crease, made by folding at a suitable distance from one of the edges. Without the help of this special binder, an even width may be attained by means of strips of wood, having two parallel stops at adjustable distances, one for the paper, the other for the glass. It is sometimes preferred to bind with strips much wider than required, the excess being cut and removed after wetting. In any case care must be taken to ensure correct joints at the corners, the binding overlapping slightly, the end of the upper strip being cut at an angle of 45°.

PART 5

SPECIAL TECHNIQUES

CHAPTER XLVIII

COPYING; RESTORATIONS TO THE VERTICAL

878. Copying by Contact Printing. An original on paper of homogeneous structure, even though rather thick, may be copied by transmitted light, provided the back of the paper bears no imprint or note. This is often the quickest way of reproducing originals. For purely record purposes, satisfactory copies can be obtained in this way from photographs of card substance (postcards); owing to the great diffusion of light by the base, an imprint of grey colour on the other side does not usually appear in the copy. It is useless, and often dangerous, to oil the paper in order to increase its translucency, for the only advantage is a slight reduction of the time of exposure, and this is more than balanced by the time taken to oil the paper and then free it from the grease.

The grain of the paper can be almost completely eliminated if the copy is made by yellow or red light, since paper becomes increasingly transparent as the wavelength of the light is increased.

It must be borne in mind that the contrast of an image is always considerably lower when it is examined by transmitted instead of reflected light. This loss of contrast must be compensated for by choosing a slow emulsion capable of yielding a contrasty image by suitably prolonged development.

These same working methods are applicable to the copying of the structure of leaves or of anatomical sections. As these sections are generally mounted between glass cover slips, it is necessary, in order to obtain a sharp image, to place them at a considerable distance from a source of light which is nearly a point, or to use the beam of light thrown by a condenser (§ 632).

In the case where the copy is made by contact between the back of the document and the sensitized surface (as is usual when copying tracings) the tracing must be as transparent as possible; the greater the diffusion due to the tracing paper, the less clear and contrasty

will the copy be. The density range of the tracing, which is equal to the actual density of the lines, should be at least equal to the range of the copying paper used. This condition is amply fulfilled by lines drawn in Indian ink (density between 1.00 and 2.70) but never by pencil lines (density 0.50 to 0.85, according to whether the pencil is hard or soft).

A peculiar case is presented by very large drawings which have to be copied without distortion (optical distortion or distortion due to the paper). The drawing is produced in a stable form by the use of opaque ink on a sheet of mat aluminium coated with luminescent lacquer. This lacquer is made to phosphoresce by exposure to ultra-violet light and then immediately placed in contact with the sensitive material which has been coated on to a rigid support. The intensity of the phosphorescence becomes too weak for the drawing to be copied many times; it is therefore preferable to use a fluorescent coating which is excited by X-rays. The X-ray exposure is made with the drawing and the sensitive material pressed into close contact in a pneumatic pressure frame (L. L. A. Wynd and G. T. Lane, 1942).

If the drawing has not been made in reverse, the copies produced are reversed; to avoid any difficulty, a negative is first made on the aluminium sheet which has been coated with a fluorescent layer and then with an impermeable varnish followed by a sensitive coating. This negative gives positive copies, in the normal sense, on all sensitized supports. These working methods are employed particularly in the aircraft and automobile industries to replace templates marked out by hand.

879. Copying by Contact in Reflected Light. The possibility of copying by contact a black and white original (not in tones), either opaque or with an imprint on the back, was pointed out as long ago as 1839 by A. Breyer, and the method to be used was described by P. Yvon (1891). This process is sometimes attributed to J. H.

Player (1896) and called *Playertype*, although this author only drew attention to a fact already known. A yellow filter is placed in a printing frame, and on it is laid the sensitive surface (plate, film, or paper), with the emulsion side towards the inside of the frame. The face of the original to be copied is laid on the emulsion. A sheet of black paper is placed over the original, and the printing frame is closed and exposed to light for a time which has been ascertained by a few tests. Under these conditions, the light coming to the emulsion before reaching the original tends to fog it uniformly, but a portion of the incident light passes through the sensitive coating and reaches the image to be copied. This light is absorbed by the black portions and diffused by the white ones, which latter return it to the sensitive emulsion. Very approximately it may be said that opposite the white areas the emulsion receives twice as much light as opposite the black ones. By using a very contrasty, non-colour sensitive emulsion and an energetic developer heavily dosed with bromide (§ 393), a negative is thus obtained which may not be perfect, but is quite usable.

It is clearly not possible to use anti-halation coatings or coatings of several superposed emulsions. Special papers are produced coated on to a thin base (85 g/sq m). They are very white, very lightly baryta-coated and coated with a slow emulsion (much less rapid than ordinary silver chloride papers) which allows them to be handled in weak daylight.

The copy becomes more contrasty since the light absorbed by the sensitive layer only represents a small fraction of the active incident light. Consider a document the reflection densities of which are respectively 0.8 and 0.05; the quantities of light absorbed during the transmission and reflection of the light in the sensitive layer will be 90.8 and 90.05 per cent if the sensitive layer absorbs 90 per cent of the active incident light, or 17.2 and 10.45 per cent if the emulsion only absorbs 10 per cent. In the first case, the contrast ($90.8/90.05 = 1.008$) is totally insufficient to register an image whilst, in the second case, it has a value ($17.2/10.45 = 1.64$) sufficient to obtain an image in an emulsion of very high contrast. A yellow filter of appropriate absorption, with a silver chloride emulsion, enables only those wavelengths to reach the copy which are at the limit of the spectral sensitivity of the silver salt, which radiations are least absorbed.

A yellow filter may be made experimentally by dyeing, in a 2 per cent solution of tartrazine, a gelatine-coated plate (a photographic plate fixed out, washed and dried) which is quickly rinsed, dried and bound up with a plate of clear glass for protection. Yellow lamps can also be used. The yellow filter reduces the structure of the paper forming the support for the emulsion.

For commercial use either paper or film is used which carries a silver halide emulsion (a high proportion of chloride) which is weakly orthochromatic and of high contrast.

This method was for a long time used only occasionally for preparing lantern slides from illustrations in scientific or technical works. It has acquired a certain industrial importance, particularly for reprints of books and the general reproduction of documents where low cost and speed are of principal importance.

880. Arising out of sensitometric tests made on a gelatine-chloride paper intended for this copying process (P. Ernst and J. Rosenheck, 1929) it has been shown that the same paper, used for contact copying by transmitted light and then for copying by the reflex contact method using the same yellow filter, after development under identical conditions, exhibits the following characteristics—

Contact Copying	Contrast Range	Gamma	Density Range
Transmitted light	8 : 1	2.75	1.8
Reflected light	2.5 : 1	1	0.8

The fact that the reflex copy only differentiated tones over a narrow contrast range shows, on the one hand, that this method is not applicable to copying half-tone images and, on the other hand, that it leaves scarcely any latitude in controlling the exposure time for the copy; the low values of the contrast and of the density range of the negative obtained compel one to use a paper of high contrast for printing the positive.

The following method is recommended for finding the optimum exposure time (L. Lobel, 1935). A test object is made up by mounting, side by side on one piece of card, two strips of paper, one black, one white. Using the normal reflex copying technique, the test object is copied on the paper under test, using exposure times which form a geometrical progression based on 2. After developing to completion, the transmission densities are measured of the

two areas, step by step, corresponding to each exposure. The exposure is chosen which produces the greatest density difference. Starting with a result in which the densities, measured by reflection, differ by 1.15, to give the best copy on a special paper, the density range can be as low as 0.8 (densities 0.9 and 1.7 corresponding to a brightness ratio of 1.58:1). On ordinary high-contrast printing papers, however, (bromide or chloro-bromide) this density difference does not exceed 0.4.

The density range of the copy will be considerably reduced if an exposure time is used for the copy such that the density of the image of the blacks is less than the lowest density lying on the straight-line portion of the characteristic curve.

881. Distortion of the paper in the course of handling precludes the use of methods described above when making reproductions of high precision; two variations, however, can be used.

The reflex copy may be made on the type of paper in which the emulsion layer can be transferred dry to a non-shrink support between exposure and development.

Reflex copying can also be carried out using special plates (G. W. W. Stevens, 1944). Plates produced by coating glass with special emulsions give images of too low contrast to be useful. In fact, in the case of paper, light which has passed twice through the emulsion is, for the most part, returned to it by the support; it is lost, however, if the support is transparent. The difficulty has been resolved by coating, as a substratum, a special diffusing layer, consisting of an almost insensitive emulsion of a silver salt, which plays no part in forming the image, but which dissolves out during fixing and thus leaves a negative on a transparent base.

In the course of experiments undertaken in perfecting this method, it was found that the quality of the black of the document being copied has very little influence upon the density range of the negative (black and deep grey give the same results) whereas the quality of the whites has a considerable effect. The paper can be stained yellow without disadvantage since the copy must be made by yellow light, but a paper which is somewhat grey or stained a broken yellow cannot give the maximum contrast.

Exposure must be adjusted so that, after development to the maximum gamma, a density of about 0.4 is obtained in the image of the

blacks, when measured by transmission and after deducting the density of the base.

882. When using normal emulsions containing silver salts it is possible to obtain negative copies only. Direct positives having pure whites can be produced on cellulose acetate films which have been sensitized with diazo compounds and exposed through a screen (120 lines per cm) followed by semi-moist development (Rétoché process; L. and K. van der Grinten, 1938). The films so obtained can be kept just as they are and used to produce further prints on diazotype paper by contact printing or, when backed by a sheet of adhesive paper, they may be viewed by reflected light.

Diazotype coatings absorb very strongly the rays to which they are sensitive and cannot be used for making reflex copies under the same working conditions as are used for copying by means of silver emulsions. The sensitive salt which forms a continuous layer, is destroyed by the incident light at the same rate opposite the blacks as against the whites of the document. By interposing a screen (transparent squares on a black ground) the diazo compound is destroyed only by the light falling on the part nearest the surface of the sensitive layer, the remainder being available for the copy since, on the almost microscopic areas thus protected, the diazo compound is only destroyed opposite the whites of the document by the light which the whites diffuse. By the light from a 3-kW arc lamp, a print is obtained in about 80 seconds.

883. Simultaneous Production of a Reflex Negative and a Reversed Positive Print. An interesting technique, described by A. Rott (1939) under the name of "inversion transfer by diffusion," enables one to produce, in a single operation, the usual reflex negative and a positive print capable of being read normally. The positive is produced on paper coated with plain gelatine by the silver halide not used in forming the negative image. The sensitive paper is of the type normally used for reflex copying; the paper which receives the positive image contains a small quantity of hypo in order to dissolve the silver salt, and traces of silver or colloidal silver sulphide act as nuclei for the deposition of silver reduced by the developer.

After exposure to the printing light in the usual way, the sensitive paper is given normal development for one minute and laid face upwards on a sheet of glass. To the image side the gelatinized transfer paper is applied

after it has been softened by immersion for a few moments in the developer, perfect contact being ensured by rubbing down with a squeegee. The two sheets are separated after a few moments (the contact may be longer in the case of images without half-tones); the transfer paper bears a positive image which it is sufficient to rinse, but the negative must be fixed and washed.

An analogous method enables enlarged positives to be produced from a transparency (colour transparency or ciné film) on to a double-coated paper which bears, next to the base, a tanned gelatine layer, then an untanned silver bromide emulsion of low contrast which is removed by stripping with warm water after development, transferring and checking in cold water. The image colour of the positive thus produced is not always perfectly satisfactory but it can easily be modified by toning.

A commercial office document copying process based on this principle is known as *Agfa Copy-rapid*. Here the exposed emulsion and the receiving paper are brought into contact in the developing solution and peeled apart again after a short time (E. Weyde).

884. Copying with a Camera. Although, in principle, copying may be undertaken with any camera having a sufficiently long extension, the adjustment of exact parallelism between the planes of the original and of the sensitive surface is extremely tedious, especially if the copy requires to be made to a given scale, unless specially built apparatus (§§ 152 to 154) is available to facilitate the work.

Some vertical enlargers (§ 637) can be used as copying cameras. The easel and the dark slide are in an horizontal plane, and the axis of the lens is vertical. The parallelism of the two conjugate planes can then be tested very simply by means of a spirit level.

In the absence of a permanent installation, it is always possible to make an arrangement to simplify the repeated adjustments otherwise needed on each occasion. It is, for instance, possible to rig up a form of copying bench by mounting the camera on a carriage which can be slid along grooves or rails placed on a table, marks being drawn so that the table can be always brought to the same position. The easel can be fixed permanently to a wall.

If there is insufficient room to use the lens with its axis horizontal, a worker with any manual skill could easily arrange for the camera

to move in vertical slides, the original to be copied being placed directly on the floor.

885. The simplest way of ascertaining the parallelism of the planes of the easel and of the focusing screen (assumed to occupy the same position as will be occupied by the sensitive surface) when these planes are not horizontal consists in using a mirror of such size that it can be exchanged for the focusing screen. If an assistant is available, the mirror can be much smaller, for the assistant can hold it against the focusing screen when the observation is made. First fix this mirror to the easel facing the camera. Remove the lens board and the focusing screen, go behind the camera and, looking through it, sight the mirror along one edge of a flat ruler. The ruler should be fitted on an easily movable support such as a tripod stand, head-rest, etc., so that the image of the ruler edge reflected by the mirror forms an exact prolongation of the ruler edge itself. The ruler being then left undisturbed and fixed, the mirror is put in the place of the rear surface of the focusing screen with its reflecting face turned to the back of the camera. If the mirror is in a plane parallel with the easel the coincidence of the line of sight and of its image will still be seen. If this be not the case, the adjustment of the camera or of the easel must be modified until the sight-line coincides with its image in the two positions given to the mirror. For the adjustments of the high order of precision required in a camera for copying maps, and of its various accessories (prism, mirror), the methods described by E. Deville, Surveyor-General of Canada (1912) must be used.

886. Factors Affecting the Sharpness of Copies. A copy is perfect only if absolutely sharp and if the thicknesses of the lines are reproduced on the same scale as for the entire image. To thicken the lines in a very small-scale copy from the negative of a document, it has been suggested that a glass strip with parallel surfaces be turned in front of the lens around the optic axis, the strip being the more inclined on the axis the greater the desired thickening of the lines (Schlotzer, 1933). In the copy of a pen-and-ink drawing, for instance, if the lines are thickened by a few hundredths of a millimetre only, the effect is considerably heavier; on the other hand, if the lines are finer the drawing loses all strength. There is a risk of the lines being made thinner by irradiation in the case of over-exposure; a negative having very fine lines must be somewhat under-exposed, a low

density being thus obtained (preferably less than 1.0). The negative thus obtained can be intensified, however.

It is necessary to remember that stopping down the lens excessively may impair the sharpness instead of improving it (§ 55). The better the quality of the lens, the larger the aperture which it is best to use. Apertures of diameters smaller than one-fiftieth of the extension should be avoided.

An original that is not perfectly dry when it is placed on the easel may shrink progressively under the effect of the heat of the lamps, and the sharpness may suffer in consequence. On the other hand, the heating of the layer of air between the lens and the original, if the lamps are too near the latter, may cause currents similar to those that are seen when sighting objects behind a flame (F. Dogilbert, 1909).

Vibrations of the floor may render it impossible to obtain a sharp image (§ 152). It is at least advisable to avoid walking around the camera during the exposure, and particular care must be taken not to knock against it, even if it is suspended.

The model must always be placed before a black background covering the whole of the field embraced by the lens, so as to decrease the risk of fog and the weakening of contrasts by successive reflections between the components of the lens (§ 58), and diffusion by the interior surfaces of the camera.

887. Choice of Sensitive Material. An increase of contrast always increases the sharpness of the images by merging in the white of the paper any unsharpness resulting from the various circumstances mentioned above. Originals which include only black and white (printed matter, wood engravings, lithographs, geometrical drawings, pen-and-ink drawings) will therefore be photographed best on the special emulsions for process work. Originals in black on a tinted or stained ground, or those in colours (architect's or engineer's blue-prints, etc.), are reproduced by means of process panchromatic emulsions with the aid of suitable colour filters (§ 119).

In the case of full-tone originals (and among these we must include pencil or charcoal drawings and copperplate engravings, of which the lines are of unequal strength) slow emulsions will be required with a very fine grain, or lantern plates, but not the special emulsions of very great contrast which can reproduce correctly only a very short scale, even if development is not forced.

Warm-tone photographs (P.O.P. prints, red or sepia-toned bromides) are nearly always falsified by copying with non-colour-sensitive emulsions, the darker tones tending to merge into the deepest shadows. All difficulty will be avoided by using an orthochromatic emulsion with a deep yellow filter, or, preferably, a panchromatic emulsion with a medium yellow filter. These same means are suitable for copying black-tone prints on chamois or "antique" tinted paper.

888. Illumination of Opaque Documents. Whereas the distribution of illumination on a human model, an object or a group is governed by aesthetic considerations, the illumination of flat documents, for purposes of reproduction, is subject to precise rules.

The light source used for black-and-white documents may be mercury vapour lamps; for coloured originals incandescent lamps must be used.

The lamps must be placed so that their reflections do not appear on the document (particularly in the black lines of a drawing). This condition is easier to fulfil if use is made of a lens of long focal length. If reflections are seen, move the lamps parallel to the document in the direction of the lens axis.

The considerations in § 10 on the distribution of illumination in a plane illuminated by a point source (or a line source) enable one to calculate the total illumination at each point in the plane, lit by several lamps. Suppose that one has to illuminate a square by four lamps roughly equivalent to point sources; by placing each lamp opposite to each of the four corners of the square and at a distance from the document equal to or slightly less than half the diagonal of the square, illumination is uniform to within less than 4 per cent. The average amount of light on the copy will be 1.45 times that given by a single lamp, when measured at a point on the copy closest to the lamp.

Absolute uniformity is neither necessary nor desirable. It is a help to compensate for the variation of illumination of the image, from the centre to the edges of the field by increasing the illumination towards the edges of the subject. By moving a photo-electric exposure meter or an illumination meter across the field of the document, it is possible to measure the relative illumination at various points.

When illuminating a document by means of tubular lamps, the length of the tubes must be substantially greater than the larger dimension

of the document being copied, the more so the farther they are apart. If for example, tubes of length 1.25 metres are placed 50 cm from the document, the illumination is only uniform, in the direction of the lamps, over a length of about 60 cm.

889. Photography of Originals on an Opaque Base. The grain of the paper can generally be subdued by greatly-diffused illumination, slight departure from sharp focus, and somewhat ample exposure.

The texture of the paper is emphasized chiefly by the reflection of light on the convexity of each grain. Thus any means of suppressing these reflections results in the disappearance of nearly all traces of the structure of the paper, at the same time scratches and local abrasions due to rubbing are reduced or suppressed, and the contrast of the image is increased.

The most perfect means of eliminating all reflections consists in lighting the original by polarized light and by suitably orientating a polarizing screen fitted in front of the lens (§122).

If a vertical camera is available, a good method consists in copying the original immersed under a few millimetres of water in an ordinary photographic dish with a flat bottom (A. L. Donnadieu, 1883), care being of course taken to avoid all movements or currents of air liable to ripple the surface of the water. Immersion, preferably in a tank with vertical sides like an aquarium, avoids the reflections which are always troublesome in the photography of jewellery, gold and silverware, etc., the photograph being taken vertically or horizontally according to the nature of the articles.

Immersion also improves the reproduction of all photographs on mat or semi-mat papers; it is indeed well known that such papers have a more extended scale of tones when wet than when dry. This method is especially necessary when the print is to be made on mat paper, as otherwise there will be a cumulative loss of detail and of modelling.

In the absence of a vertical copying camera, it may be possible to immerse the print in a vertical glass tank with plane walls, but it is simpler to soak the print in water containing about 10 per cent of glycerine and to apply it by its face to a sheet of flawless glass, just as is done when enamelling prints, or against the gelatine surface of a plate cleared of silver bromide, the pressure of the squeegee then causing the grain of the paper to penetrate the swollen gelatine. The glycerine prevents drying and

the resultant risk of sticking to the glass. After the copy has been made, the print is well washed, dried, and mounted again if necessary. It is often sufficient to grease slightly with paraffin oil the image side of the print, which after copying is wiped and then de-greased with benzene or carbon tetrachloride.

The use of infra-red, which is reflected in very different proportions by metallic silver and by its amalgam which forms the image has permitted very contrasty copies to be made of Daguerreotypes, which gave only poor results with an ordinary emulsion (B. Svenonius, 1934).

890. Lighting of Originals to be Copied by Transmitted Light. In the copying of transparent originals on an enlarged or reduced scale uniform illumination can be obtained by a diffusing surface such as an uncreased sheet of white paper, the front surface of which is illuminated according to the rules already stated (§888), a sheet of thin opal glass, or by a series of sheets of ground glass illuminated from behind (§635), by means, for instance, of tubular electric lamps parallel with each other, or, if the surface to be illuminated is not great, by a single mercury tube of M-shape. A photographic print with excessive contrasts can sometimes be improved by copying if illuminated partly by reflected and partly by transmitted light, the contrasts being reduced proportionally as the lighting by transmitted light preponderates.

In all cases where the photographer is satisfied with daylight, in spite of its fluctuations, the entire apparatus (camera and easel) is directed towards the sky, or at least towards a window, outside which a mirror or diffusing screen of adequate size supplies the necessary illumination.

Unless a triple-body camera specially adapted for copying is used (§152), it is at least necessary to cut out the major part of the light reflected on the front surface of the original illuminated by transmitted light; otherwise the copy will be badly fogged or covered with reflections. It is sufficient to have a tunnel of black fabric enclosing four sliding rods (or four cords) passing from the adapter frame (serving as the object-carrier when copying a transparency) to the front of the camera; complete light-tightness is not necessary.

891. Commercial or Industrial Photo-copying of Documents. Photographic copying of documents, bills, letters of interest to various departments of a business, etc., has become of great importance during recent years. Several banks and large

organizations have set up photographic departments and photographers have specialized in this work.

Excluding for the moment microcopies of greatly reduced scale (§ 893) these photographs are usually made at a scale of between $\times 2$ and $\times 0.5$ by means of apparatus which, with or without reflectors, allows of lateral reversal of the image.

Lateral reversal is necessary when the reproduction is made directly on to the paper which forms the final copy, either as a negative or a positive.

When the camera includes a reversing prism or mirror, several positive copies can be made by re-photographing the negative obtained in the first stage in just the same way as the original document.

Automatic machines have been produced, which are often very complicated, for photographing in rapid succession documents placed into a magazine in files. The copies are made on paper and may be cut after each exposure or left in a roll. The documents are brought automatically in front of the lens, photographed and returned to a second magazine.

892. Expert Photographic Examination of Documents. The expert photographic examinations of documents may be classed under—

(a) The comparison of handwritings or of type-written matter.

(b) Investigation of forgeries, erasures of various kinds, and over-writing.

In work of the first group photography is used only to make a permanent record of the conditions revealed by examination of the documents by means of lenses of high magnifying power, and the photographic work is usually directed by the expert entrusted with the examinations. The originals to be compared must be copied under identical conditions with extreme sharpness, and enlarged to the same scale, so as to show the hesitations of a forger in imitating a handwriting, or the individual defects of the type-letters which may differentiate typewriters of the same make. For photographing violet and red typescripts, a green light-filter (such as is used for trichromatic selection) must be used in conjunction with a panchromatic emulsion.

The photographer plays a more active role in work of the second class, which often allows of the detection of differences which it is impossible to observe visually. The document is

photographed with an enlargement of six to ten times linear, if possible with a lens of short focal length.

Erasures are brought out by using a lighting which just grazes the surface, or by means of transmitted light. Erased texts can sometimes be photographed by the method used for deciphering palimpsests (old parchments written on again after removal of the original writing by scraping or rubbing with pumice). The original is "lighted" with ultra-violet light (rays from a mercury arc in a quartz bulb) filtered through a black nickel oxide glass (Wood's glass). The paper becomes fluorescent except in the parts still impregnated with the iron salts of the ink, and may then be photographed through a filter absorbing the ultra-violet (R. Koegel, 1914), for instance, a solution of sodium nitrite in a trough with glass sides.

The slight traces of yellow remaining after chemical erasure of writing can be accentuated by photographing with an ordinary (non-colour-sensitive) emulsion, or, better still, by wet-collodion, the document being illuminated by a light rich in violet and ultra-violet rays, such as an ordinary mercury arc.

Differences between two inks of the same appearance can sometimes be rendered visible by placing the document for about 8 days in contact with a print-out paper, which is then exposed uniformly to light, the text (or a mechanically or chemically erased text) appearing lighter or darker than the ground.

Another more general method for differentiating between inks of the same appearance consists in photographing the document several times, each negative being made with a light-filter of different colour; differences of composition are then often revealed by differences in the depth of the lines.

Finally, photo-micrographs of low magnification ($\times 20$ approximately), either single views or stereoscopic views, sometimes permit of ascertaining in which order two lines that cross have been drawn, and thus of detecting additions made after the writing of the main text.

893. Reproduction of Archive Documents at a Reduced Scale. Reduced-scale reproduction (0.1 to 0.05 approx.) of documents from archives or libraries on to standard double-perforated 35-mm ciné film (image size 24×36 or 18×24 mm) was suggested by R. B. Goldschmidt in 1907 and came into use about 1925. Several large libraries, and documentation services provide, at a moderate cost, copies of valuable

manuscripts, out-of-print books and articles published in inaccessible journals. Certain libraries also have reading rooms for films reproducing rare works in the possession of other libraries. Lastly, commercial and industrial organizations have made, in this manner, compact duplicates of their essential documents, storing the originals in a separate place, by way of a precaution against all risks of destruction.

Contrary to logic and also to the decisions of the International Congress of Photography, popular opinion has given the name "photomicrographs" to these reproductions of documents to which should be given the names of "microphotographs" or "microcopies," the word *photo-micrograph* always designating photographs obtained by means of a microscope and the images of which are at a scale of much greater than unity.

The films used are non-inflammable, made of acetate base (see § 244 for optimum conditions for storing such films) carrying a fine-grain emulsion of high contrast which may be of silver bromide or chlorobromide, colour-sensitized or not.

More or less automatic machines enable successive pages of a book to be reproduced or documents (letters, cheques, etc.) fed from a pile into the machine.

Microfilms can be read by means of a magnifier attached to a holder for the film but this method of reading is tiring. It is generally preferable to examine an enlarged image from a projector, the image being thrown either on to a ground-glass screen or a white paper surface.

This method of copying was used by Dagron on the suggestion of D. C. R. d'Almoldan during the siege of Paris (1870-71) for sending to Paris, by carrier-pigeon, official documents and private correspondence.

Very small-scale reproductions are nowadays used as micrometers and graticules in various optical instruments (graduation of stereoscopic rangefinders, etc.) Such images may be produced in apparatus resembling a microscope used in reverse upon an emulsion identical with that used for collodion papers. The limit of resolution of such emulsions is then lower than 0.001 mm; gelatine-bromide emulsions of the Lippmann type, thinly coated, can resolve about 1,000 lines per mm, if the test object is one of high contrast.

894. Restoration to the Vertical of Photographs Taken on an Inclined Plate. A photograph taken on an oblique (tilted) plate or film

may be transformed into an image identical (except for the scale) with the one which would have been obtained on a vertical plate (architectural photographs) or on a horizontal plate (aerial photographs for map making). The problem of this rectification of a distorted image was studied especially by C. Welborne Piper, de Romance, and T. Scheimpflug in 1898, and by L. P. Clerc and by G. Labussière (1917).

For this rectification, use is made of the formation of a sharp image of a plane placed obliquely on the axis of the copying lens already studied in § 66. If need be, the slightly convergent vertical lines of a photograph taken with a tilted camera can be brought back into parallelism by presenting obliquely to the axis of the copying lens either only the negative to be copied or only the sensitive plate on which the copy is to be made, the lens being stopped down until the requisite depth of field or depth of focus is obtained, but the image thus produced is usually not identical with the one that would have been obtained direct under normal conditions; the vertical lines are either lengthened or shortened relatively to the horizontal ones. Besides the stated conditions for obtaining a sharp image or for throwing back to infinity the vanishing point of the vertical lines (or the vanishing points of the horizontal lines), there is a further condition to be satisfied, in the absence of which the rectified image is not similar to the normal image, but is a "squat" or drawn-out transformation of it. By this is meant a deformation such that the image of a square becomes a rectangle, one of the dimensions being stretched or compressed. (It may be added that care is not always taken to fulfil this condition in rectifying an architectural negative, so that measurements made from the final print would lead to serious errors.) We will only state this condition without giving the proof. All details will be found in *Applications de la Photographie aérienne*, by L. P. Clerc (Paris, 1920), Chapter XII.

The intersection of the plane of the negative with the vertical plane or with the horizontal plane, which we will define later, must be at a distance from the entrance node of the rectifying (copying) lens equal to the distance at which it was (at the time the view was taken) from the exit node of the lens taking the view. The vertical plane mentioned is the plane formed (at the time the view was taken) by a horizontal, perpendicular to the optic axis, containing the exit node (in the case of rectification on a

vertical plane; this intersection is the horizontal of the negative containing the vanishing point of the vertical lines). The horizontal plane mentioned is the plane passing through the said exit node (in the case of rectification on an horizontal plane; this intersection is identical with the horizontal line).

To permit of a negative being properly corrected for distortion it is necessary to have a camera of which the object (transparency) holder and the rear body are both fitted with swing movements, the axes of the swings being parallel to each other and perpendicular to the optic axis. If it is desired to avoid much fumbling in the adjustment of the focus after use of the swings, the axes of the swings must be contained in the respective planes of the image to be rectified and of the sensitive surface on which the rectified image is being made. The negative must be carried on a revolving carrier permitting its principal horizontal line to be placed parallel to the axis of the swing. In order to control the scale of the rectified image it is necessary that the negative holder should slide in its plane, so as to satisfy the condition of non-deformation. Instead of this, the decentering of the negative may be replaced by that of the lens, but the adjustment is then more difficult. Finally, to make the rectification possible, it is necessary to use a lens with a focal length much shorter than that of the lens with which the view was taken.

895. A particularly simple case is that where the planes of the negative and of the sensitive surface cut the optic axis of the lens used for rectification at the symmetrical points (§ 63). In this case the angles through which it is necessary to swing the conjugate planes are equal. If, furthermore, the rectification is done with the same lens as used for the view, the angle formed by the two conjugate planes with the normal planes at the optical axis is exactly equal to the angle formed by the lens axis (when the view was taken) with a horizontal plane (rectification on a vertical plane) or with the vertical (rectification on a horizontal plane). All deformation will be avoided by bringing the principal point of the negative to a distance e from the corresponding axis of swing determined by the equation $e = F \tan(a/2)$, F being the focal length of the lens and a the angle in question.

896. Hand cameras which have no rising front are in general use and this has led to a considerable increase in the number of amateur

snapshots the verticals of which converge either towards the top or the bottom of the picture. It would be desirable for the establishments undertaking amateur work to carry out correction of these prints. The practical men, frightened by the mathematics brought into play, elementary though it may be, prefer to abstain. By methodical trials, it is possible to arrive at very satisfactory correction without the use of any calculation (D. Charles and A. Block, 1945). The negative is set square to the

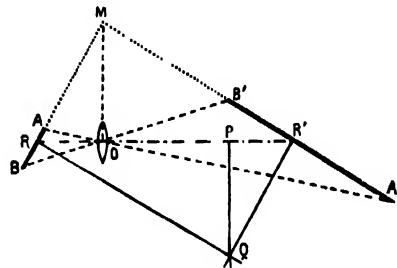


FIG. 48.1. AUTOMATIC CORRECTION OF CONVERGING LINES IN ENLARGING (Carpentier)

optic axis; the paper holder is then tilted until the verticals are restored to parallelism. The image is then very unsharp. The negative carrier is then tilted to restore sharpness, but this upsets, to some extent, the parallelism of the verticals. These two operations are then repeated in the same order until the image is sharp and the verticals parallel.

The image is usually distorted; the height of the image is stretched or compressed relative to its width. In order to restore the proportions of the image, if not exactly, at least tolerably, the negative carrier and the paper holder are moved in a direction at right angles to their axes of tilt until the most accurate impression is obtained. Correction produced in this way may be made exact if the subject includes a vertical line on which three equidistant points can be identified; it suffices then to adjust the amount of de-centering until these three points are once more equidistant in the image.

897. Various arrangements have been made or suggested to ensure the automatic linkage of the swing movements of the two conjugate points. We will describe only the rectifying enlarger constructed in 1900 by J. Carpentier for the enlargement of negatives taken with a camera not fitted with rising-front movements

and which is therefore often tilted when photographing tall buildings or monuments.

A triple body camera represented in diagrammatic form in Fig. 48.1 comprises a negative carrier AB and a dark-slide for the sensitive paper $A'B'$, which swing respectively round the axes RR' contained in their planes of support. To ensure the intersection of these two planes in M in the plane perpendicular to the optic axis of the objective O , two levers QR , QR' are fixed to the end bodies of the camera and are pierced with grooves following the perpendiculars at R and R' to the planes AB and $A'B'$. A gudgeon Q moves without friction in these grooves. This gudgeon is forced to move in a groove PQ of the base, perpendicular to the optic axis, in such a position that the distances OR and PR' are equal.

The magnification, measured on the axis of tilt, does not vary. In order to carry out, in a single operation, rectification and setting of the scale of an aerial photograph, a working model was prepared in 1917 by L. P. Clerc for

giving automatic correction with variable magnification, using the Carpentier linkages for tilting and Koenig's linkage (§ 69) for maintaining the separation of the axes of tilt. This apparatus was re-invented by A. Odencrants in 1934; the same arrangement has been embodied in an apparatus (F. Ferber, 1942) which automatically ensures that distortion shall not occur.

898. In addition to the already-mentioned applications of the method of rectifying a distorted image, the same methods make it possible to distort systematically any image so as to obtain, for instance, a transparency which, when projected obliquely (projectors for advertising purposes forming on the pavement in front of a shop window an image which is usually badly distorted), will be brought back to normal proportions.

In thus distorting an image and then rectifying it without observing the condition of non-deformation, it becomes possible at will to draw out or compress one of the dimensions relative to the other in any desired proportion.

CHAPTER XLIX

SLIDE MAKING AND PROJECTION

899. Introductory Note. The modern slide projector is the result of the development by successive stages of the old "magic lantern" supposed to have been used by the priests of Ancient Egypt, and of which a description was given in 1461 by C. Milliet de Chales. The improvement of optical arrangements, the discovery of powerful sources of light, and then the use of photographic methods (Langenheim, Duboscq, 1851) for producing lantern slides (previously made by painting on glass)—all these steps extended considerably the scope of the projector. Its employment in scientific teaching is due to D. Brewster and to the Abbé Moigno (1872) among others. It has now become the indispensable adjunct of nearly all branches of teaching.

LANTERN SLIDES

900. Standard Sizes of Lantern Slides. The dimensions recommended for lantern slides by the International Congress of Photography (Paris, 1889) have been generally adopted in all Continental countries. Great Britain and the United States have special sizes. The sizes given below and in Figs. 49.1 to 49.4 are the maximum dimensions of a bound slide. The actual dimensions of the glasses are about 1 mm ($\frac{1}{25}$ in.) less. The sizes of the useful portion of the image (opening in the mask) are obviously optional, the values given being about their maximum limits.

Increasing use of miniature cameras has led to the introduction of a new size 5×5 cm (49 ± 0.5 mm) of which the picture dimensions used are 24×36 mm. Single frames of positive film may be mounted between glass plates or held in metal frames in which the film is gripped between ridges in the two frames. There are on the market still projectors for showing standard 35-mm ciné-film carrying frames of 18×24 mm and 24×36 mm, or the 5×5 cm slides as desired.

901. Photographic Lantern Slides. Lantern slides are usually made on special plates yielding images of black tone (§§ 708-13) or of warm tone (§§ 719-22), with the facility of toning or dyeing (§§ 735-56). They are sometimes also

made by various pigment processes (§§ 803 and 821-5).

It is advantageous to vary the colour of the slides of a set, so as to avoid monotony, but it is necessary to avoid too vivid colours in striking contrast with the average colour of the subject.

When diagrams,¹ charts, or numerical tables are shown in alternation with views, etc., in tone, the excessive brightness of these subjects, with extensive areas of white, is so dazzling as to prevent the next views from being seen satisfactorily. Such alternations of semi-darkness and light may be fatiguing. To prevent this, it is often preferred to project the negative, instead of a positive, of the line subject. Such negative must not be too dense. In order that the rod, with which the lecturer points out details on the screen, may be visible, it is advisable that such negatives be toned to a warm colour.

For the printing of lantern slides by contact there are various types of special printing frames allowing the printing aperture to be centred over one part or another of a larger negative. There are also available commercially reduction cameras (similar in construction to box-form enlargers) for copying on a reduced scale from large negatives. Reduction from negatives of very large size (such as X-radiographs) is usually done in a triple-body camera with an arrangement for illuminating the negative with diffused light.

While, with some practice, it is usually possible to judge satisfactorily the colour and contrast of a lantern slide by holding it at an angle of 45° in front of a white background which is uniformly illuminated (care being taken to avoid reflection of light from the image), it is always well to test the slides by passing them through the projector in the normal manner. This precaution is specially necessary in the case of slides which have been toned to another colour than black; while they may appear perfect when viewed direct, they may sometimes cause an unpleasant surprise when projected.

¹ After adjustment to the scale desired, the thickness of the lines must be between 0.3 mm (curves) and 0.05 mm (lines of the squared ruling); the lettering, in strokes of uniform thickness (0.15 to 0.10 mm), must be 1.5 to 1 mm high.



The stronger the source of light, the more contrasty the slide must be. Slide projection in the family circle or before a small audience with lights of low intensity calls for comparatively soft slides, which would seem somewhat flat if shown in a large hall with the customary high-power illuminants. The contrast of the projected image is decreased, on the one hand, by reflections in the optical system of the projector (§ 58) and, on the other hand, by the light scattered by the walls of the room and by the dust or smoke suspended in the air.

902. Diagram and Notice Slides. To save time, a notice or drawing may be made directly on the slide without the aid of photography.

The notices can be written or typed on thin paper, gelatine, or Cellophane, inserted between two sheets of "carbon paper" as used for obtaining carbon copies. In this way two identical impressions are obtained, one on each side, and these reinforce each other.

The writing or drawing may also be done with Indian ink on first-class tracing paper, or with pencil on ground glass; or, again, it may be done by scratching with a stylus on a piece of glass previously prepared by coating with one of the varnishes used by copperplate etchers.

The slide may also be made by writing with copying pencil on smooth paper. This is then applied for 15-20 seconds to a glass covered with gelatine (e.g. a fixed photographic plate, which must have been washed and dried). This is dipped in water and blotted with a non-fluffy blotting paper when about to take the impression. The progress of the operation is followed through the glass. The lines pass from grey to violet in penetrating the gelatine. They do not transfer to gelatine which is too dry, and they spread if it is too wet. By using a gelatine tinted pale green, excessive brightness on the screen is avoided, and the contrast of the violet is slightly increased (A. Odencrants, 1920).

903. Binding Lantern Slides. The steaming-up which appears on a slide during projection, and the melting of the gelatine of a slide kept for some time in the projector are often due to an excess of moisture retained in the gelatine or in masks and labels which have not been sufficiently dried before the slide was bound up.

Varnishing lantern slides (§ 577), after drying by heat and then cooling, is a very useful means of preventing any re-absorption of moisture by the gelatine. Failing this, it is at least necessary to dry the slides, fitted with their masks and labels, before binding them up.

A judicious limitation of the picture area is as necessary with lantern slides as with paper prints; it can only be effected at this stage by applying a mask to the slide. If the mask is applied to the back of the slide or to the outside surface of the cover-glass, its image will not be projected sharply at the same time as that of the subject—with very unpleasant effect. Just as prints from various negatives are trimmed to different shapes and sizes, so it is not possible to get the best effect from slides if one is limited to the few masks available commercially. Among these masks those with fancy openings are to be avoided, and discretion must be used in employing circular or oval openings, which are, however, sometimes valuable to conceal a marginal defect in a slide.

The best method is to have a quantity of gummed strips of opaque paper of various widths ranging from $\frac{1}{4}$ in. to $\frac{3}{4}$ in. These can be stuck to the emulsion surface of the slide, encroaching very slightly on marks previously made with a pencil. At least $\frac{1}{4}$ in. must be left between the edge of the picture and the edge of the glass; otherwise the grooves of the carrier will obtrude on the mask, and the binding strips will have to be so narrow that they will not secure the cover-glass satisfactorily. For this it is necessary to choose as thin a paper as possible, so as not to add appreciably to the thickness of the glasses by the superposition of the strips. Paper projecting from the glasses must be cut only after the gum is dry.

Mistakes in the position of the pictures on the screen are unavoidable on the part of the lanternist unless some distinctive mark clearly shows the correct placing of the picture on each slide. The customary conventional signs are as follows, the indications of position referring to the subject seen as it is desired to appear on the screen.

- | | |
|-------------------------------------|--|
| Continental Europe (Fig. 49.1) | A white spot at the lower right-hand corner. |
| Great Britain (Figs. 49.2 and 49.4) | Two white spots along the upper edge or a single white spot at the lower left-hand corner. |
| United States (Fig. 49.3) | A white spot at the lower left-hand corner (or this spot may be replaced by a gummed red strip along the lower edge) |

These marks must be placed on the mask before binding up with the cover-glass, so that

the label may be protected as well as the picture. The white spots may be used for numbering the slides.

The free spaces available on one or other side of the mask (portions not covered by the binding strips) may be used for labels showing, for instance, the name of the owner on the right-hand side, and a brief description of the subject

middle of the strip. When a slide of dimensions smaller than the normal is being mounted, strips of card or glass of the thickness of the slide are laid on, so as to fill up the space on either side. Raise the sides of the strip to ensure a sufficient adherence for an instant, and turn the slide over. Then pass the finger or a small pad along the edge in order to cause the gummed paper to

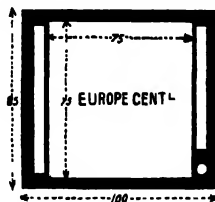


FIG. 49.1. EUROPEAN SLIDE SIZES

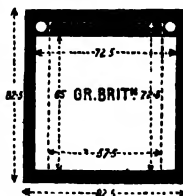


FIG. 49.2. BRITISH SLIDE SIZES



FIG. 49.3. UNITED STATES SLIDE SIZES

on the left. These labels must be sufficiently far from the spots to avoid all confusion. Papers of different colours may be used to label slides of different sets. Titles, etc., can also be written in white ink on the black paper.

The gummed strips and the labels having been thoroughly dried, the slide is bound-up with a thin cover-glass of the same size in order to protect the image against scratches and finger-markings. As far as possible these glasses must not be thicker than $\frac{1}{16}$ in., and must be free from scratches, bubbles, etc., at least in the portion covering the image. The various methods for cleaning off old negatives are described in § 585. New glasses must be washed in a warm solution of sodium carbonate, rinsed, wiped, and dried. The surface placed in contact with the slide must be perfectly clean and dry. After placing this glass on the slide, which has been dusted, and having seen that both glasses are practically the same size, the two are bound together with gummed strips.

In binding, use may be made of either one single strip, about $\frac{1}{4}$ in. longer than the total length of the four sides of the slide, or four separate strips, one for each side. Experience has shown that the use of four short strips enables better results to be obtained more quickly. The one objection to this plan is that it does not ensure complete sealing of the corners. This is of little importance if the slides have been varnished.

With a sponge moisten the back and then the front of the strip laid flat on a table. Place the slide and cover-glass (held together) along the

stick to the edges of the two glasses, and then, starting from the middle of the side, press the sides of the strip against the glasses by rubbing between the thumb and forefinger. Finally, rub towards the centre of the slide so as to stretch the gummed paper. Any paper projecting at the two ends is then cut off after another strip has been fixed. Various appliances may be bought for facilitating the binding of slides,

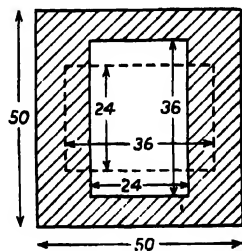


FIG. 49.4. STANDARD 2 X 2 IN. SLIDE SIZES

e.g. clamps (mounted on a base), which grip the slide and cover-glass together at the centre and permit of the two being turned round; or boards with grooves lined with felt into which the glasses are pushed, after the binding has been temporarily attached, so as to stretch the paper and cause it to adhere to the glass.

Slides belonging to different sets may be distinguished by binding strips of different colours.

904. Storing and Carrying Lantern Slides. Lantern slides are best kept in the plate boxes

(usually 8 bound slides can be put in a box, in which 12 plates are sold) with the same precautions as prescribed for negatives (§ 588).

For carrying the slides by hand, several types of boxes are used. One of the best has no grooves but has a false bottom fitted with springs. The plates are arranged on edge, separated into batches by movable partitions. The lid is either hinged or completely detachable; in the latter case it is secured by hinged brass catches. This lid contains two thick bands of rubber which press the slides against the false bottom and thus prevent all movement. The handle is a stout leather strap, completely enveloping the box, and is kept from slipping by metal saddles. Any vacant space inside the box must be packed with corrugated cardboard or balls of crumpled paper. Grooved boxes are to be avoided—they are too cumbersome—and boxes with metal handles should not be chosen, since such handles cut the fingers and are not always strong enough to stand heavy weights. (We have seen boxes supplied for a hundred slides, i.e. a weight of over 13 lb, the handles of which were fastened with quite short nails, with the heads cut through in imitation of screws!)

No attempt must be made to lift a block of slides out of a box when these slides are standing on edge. If the block is pressed very tightly the slides at either end are almost sure to be broken by the excessive pressure. On the other hand, if the pressure is less, the slides are insufficiently held, and slip and fall. First of all, place the box on end so that the slides are flat. It is then possible to take out small batches without any risk of breakage.

For sending lantern slides by post, the best method is to put them in plate boxes (of lantern-plate size) in tight packets. The boxes are secured with wide rubber bands, and are put in a strong wooden box with a screwed lid and thick packing of corrugated cardboard or felt surrounding the various boxes.

SLIDE PROJECTORS

905. Parts of the Projector.¹ A slide projector consists essentially of a light source of high power enclosed in a lamp house, a condenser, a slide carrier, enabling the slides to be changed rapidly, and a lens. The projector is usually placed on a stand, bringing the lens opposite

the centre of the screen, the stand being fitted with a shelf for the slides before and after projection. The table and shelf should be edged with strips of wood so as to form trays, in order to prevent slides and accessories from falling off accidentally, as may easily happen when working in almost total darkness. Folding tables, of which several patterns in wood or metal are obtainable commercially, are also used, or even a photographic tripod suitably wedged on a table (or several tables placed side by side to form a platform for the operator).

In addition to these normal parts, projectors fitted with very powerful light sources are equipped with cooling devices.

906. The Lamp House. The reader will find in the catalogues of makers and suppliers of projection instruments more complete descriptions than can be given here of the numerous models of projectors. Some resemble enlargers, but with more ample ventilation, permitting the use of more powerful light sources and not requiring such careful light-trapping, since any escape of light is of small account, particularly when the lantern is placed behind the spectators.

Within the limits of the money which can be spent, it is best to choose projectors the lamp houses of which are of very large size, as this gives great latitude in the choice of the illuminant. It is also advisable that the condenser be capable of insertion and removal from the side without having to take out the lamp, and that the spring platen under which the carrier slides should allow the use of other carriers than the one supplied with the lantern. Finally, the lens board must be capable of being moved out to a sufficient distance from the slide carrier to permit lenses of considerable focal length being employed. Such lenses are necessary in long halls unless the lantern is placed among the audience—an inconvenient arrangement for both spectators and operator.

Projectors of simple construction are usually fitted with condensers of 4 in. diameter, which, however, allows a slide area of only $2\frac{1}{2} \times 2\frac{1}{2}$ in. being projected. It is for this reason that slides supplied by lantern slide-publishers are usually fitted with masks with rounded corners, so as to include the whole view in the circle illuminated by the condenser. It is well to choose a projector with condensers of $4\frac{1}{2}$ in. diameter, which permits of slides $3\frac{1}{2} \times 3\frac{1}{2}$ in. or $2\frac{1}{2} \times 3\frac{1}{2}$ in. being shown. Better still, if the cost is not prohibitive, is the choice of a projector with a condenser of 6 or $6\frac{1}{2}$ in. diameter, allowing of the projection

¹ In the United States, projection lanterns are sometimes known as *Stereophones*, which the uninformed have sometimes erroneously associated with the idea of stereoscopy.

of transparencies of size $3\frac{1}{4} \times 4\frac{1}{4}$ in. on the special films for direct colour photography.

For projection in very large halls where it is not always possible to place the projector at mid-height of the screen, it is very desirable to have an instrument in which the various parts can be de-centred. This avoids the necessity of tilting, which would cause a certain amount of distortion, unless the screen be also tilted so as to be at right angles to the axis of the projection lens.

907. Light Sources. Either for home projection or for lectures before audiences limited to about a hundred people, specially designed incandescent projection-type lamps are used almost exclusively. The filament of these lamps is very compact and is made up of several helical coils arranged parallel to one another in the same plane or in two parallel planes (bi-plane lamps). The coils of the rear plane are placed so as to coincide with the spaces between the coils of the front plane thus giving an illuminating surface of almost uniform brightness. The filament area is smaller in

lamps, provided they are supplied through a resistance, or preferably a transformer.

Both sides of the filament emit light equally, therefore a concave mirror is placed behind the lamp and so adjusted that it reflects an image of the filament coils into the spaces between them. This adjustment is carried out by removing the projection lens so as to throw an image of the filament, formed by the condenser, on to a piece of white card held by an assistant at a suitable distance. Move the mirror backwards or forwards until a sharp image is obtained (the centre of curvature of the mirror is then in the plane of the filament). A slight tilt of the mirror produces an alternation of the two images (direct and reflected) of the filaments. In the absence of a reflector, scarcely 18 per cent of the total light output of the lamp is made use of; this is raised to about 30 per cent by the addition of a properly adjusted reflector. It is, alternatively, possible for this adjustment to attach an additional lens to the projection lens and so throw on to the screen a sharp image of the lamp filament.

Life of Lamp (hours)	Wattage	Voltage	Current (amps)	Filament Size (mm) (height \times width)	Total Flux (lumens)	Brightness (candles/cm ²)	Colour Temperature (°K)
15	1,000	110	9	— —	32,500	—	3,360
15	1,500	110	13.6	— —	50,000	—	3,370
15	2,000	110	18	— —	69,000	—	3,430
25	300	100	3	7 \times 8	7,500	1,215	—
25	500	110	4.5	8 \times 7.5	12,800	2,430	—
50	100	30	3.5	4.6 \times 4.6	2,400	1,070	—
50	100	110	0.9	5.5 \times 5.5	1,900	525	—
50	250	110	2.4	8 \times 8	5,800	810	—
100	900	30	30	12 \times 10	27,200	2,250	3,200
100	1,000	110	9	15 \times 13	25,700	2,320	3,100

proportion to the total luminous intensity and, for the same power, this area can be reduced the lower the supply voltage becomes. This reduction in filament-area is possible because there is less risk of neighbouring coils arcing even though they are closer together and, being made of larger diameter wire, the life of the lamp will be longer, under the same conditions.

Projection lamps are designed to have a nominal life of 15, 25, 50, or 100 hours; lamps of the shortest working life are generally restricted to cinematograph projection. The table above gives the main characteristics of several of these lamps. Comparison of the data shown makes clear the advantage of using low-voltage

Lamps should not be switched on to their full working voltage immediately but through a resistance; the length of time before switching on to full power varies with the power of the lamp.

Certain of these lamps are intended for burning vertically "cap down"; the bulb is often of tubular form. Others, having a spherical bulb, may be used horizontally. Such lamps should be used only in their recommended position.

Avoid all over-running of projection lamps and, as a precaution, regularly check the voltage or the amperage of the supply current by means of a suitable meter in the circuit.

Owing to the progressive evaporation of the

tungsten lamp filament, its diameter decreases and consequently its resistance increases. If a constant voltage is applied to the lamp the current decreases progressively, thus causing the luminous intensity to fall also. By keeping the current constant, which requires an increase in voltage, the filament brightness increases but is compensated for by the absorption of the light by the tungsten condensed on the inside of the bulb (blackening).

908. Arc Lamps. When two solid carbon rods (arc-lamp carbons) which have been connected to a source of direct current are drawn apart after having been placed in contact with one another for a moment, a stream of incandescent gas (an electric arc) connects the two electrodes. A crater quickly forms on the positive carbon at a point nearest to the negative carbon whilst a blunt point forms at the end of the negative carbon. Most of the light (95 per cent) comes from the crater (dominant wavelength 700 m μ) which reaches a temperature of about 3,500°C whilst the point of the negative carbon reaches only 2,700°C. The light emitted by the arc flame is violet (dominant wavelength 400 m μ) and is accompanied by a high proportion of ultra-violet.

The best performance depends upon the gap which, in turn, depends on the carbons. Lengthening the arc increases its resistance; the current, therefore, falls unless the voltage is increased. Owing to the burning away of the carbons the gap must be maintained either by automatic means or hand adjustment.

The difference in potential necessary, proportionately less as the current is increased, varies from 40 to 55 volts according to the nature of the carbons. Too high current produces a hissing arc which becomes unstable; the excess of carbon evaporated from the crater condenses on the negative carbon and forms a mushroom. The brilliance of the crater increases with the current density (current in amps, divided by cross-sectional area of the positive carbon) and reaches a maximum at 15,000 to 16,000 candles/cm². The area of the arc is proportional to the current density as long as the arc is silent. For equal current densities, high power arcs have a higher efficiency than arcs of low intensity. The proportion of the crater obscured by the negative carbon is reduced by diminishing the area of the latter; when this cross-sectional area is equal to half that of the positive carbon (the diameters are then in the ratio of 1:4), the rates of

combustion of the two carbons are equal (from 10 to 25 cm per hour, according to the current and the nature of the carbons) and this considerably helps in providing automatic regulation for the arc. A resistance must be connected in series with the arc in order to counter the effect of the drop in voltage which takes place when the arc lengthens.

909. For the positive electrode "cored" carbons are used (similar to the lead in a pencil) which are made of softer carbon of better conductivity than the outer shell. These stabilize the arc which, with solid carbons, tends to wander over the tip of the positive carbon. If a cored negative carbon is also used, a crater forms in it also, but of considerably less brilliance than that of the positive carbon.

When an arc is fed with alternating current two identical cored carbons should be used, the tips of which, in turn, form the principal light source. For an equal current density the temperature of the points is noticeably lower than that of a positive crater. For this reason, the light is more yellow. The lower efficiency is compensated for by inserting into the circuit a choke in place of the resistance used for direct current. The presence of the choke in series with the arc reduces the time of extinction produced by each cycle of the current. The effective voltage required for an arc of given length is a little less (30 to 35 volts) than with direct current, which corresponds to an instantaneous peak value almost equal to that for direct current. The a.c. arc emits a continuous hum.

910. By using as the positive pole a carbon with a mineralized core (containing moderately volatile metallic salts, such as fluorides of caesium and cerium) the arc can be made about five times the length, owing to its much higher conductivity. It no longer forms a proper crater, and the intensity of the incandescent tip of the positive carbon is only a little greater than that of the arc which emits about 85 per cent of the total light. The light is bluish-white; its spectrum contains a considerable number of lines and bands of great brilliance against a continuous background of much lower intensity. The efficiency is about 21 to 35 lumens per watt, according to the current and the nature of the carbons, as compared with 7 to 14 lumens per watt for uncored carbons.

With alternating current, two identical carbons with mineralized cores are used; the arc then works more regularly and with less noise. Since the arc is the main source of the light,

the periodic reversal of the current is no longer a hindrance, both cycles having the same efficiency.

When the current density of an arc (50 to 65 volts) is increased between a horizontal mineralized carbon and an inclined negative carbon, beginning at a certain value (about 60 amps per cm^2) a brilliant flame strikes out almost vertically which repels the arc (Beck effect). The intensity of the crater, greater than that of the flame, is not uniform; its maximum reaches 75,000 candles/ cm^2 (and even exceeds 100,000 candles/ cm^2 in certain types of lamp). This increase in brilliance is due to an intensification of the continuous spectrum and broadening of the bands. The conductivity of the negative carbon no longer being sufficient, a carbon coated with a sheath of copper is used which vaporizes a few millimetres from the arc. The carbons burn very rapidly and so, to avoid having to replace them so frequently, very long carbons are used.

911. For still projection (and sometimes also for enlarging on to very slow emulsions) arcs are used, the carbons of which are in line and inclined at about 30° to the vertical so that the crater faces the projection lens. With alternating current arcs are used the carbons of which are convergent so as to present both points towards the projection lens; the angle of the carbons is about 120° (60° on each side of the optic axis). Lamps with convergent carbons are sometimes fitted (when mineralized carbons are not used) with a magnetic blower, a horse-shoe electro-magnet, placed in series with the arc, which pushes back the arc and consequently allows of better use of the emitted light. In lamps, the carbons of which are in line, the same result is obtained by the use of a semi-cylindrical sheath of refractory material placed behind the arc (Marcou, 1905). This moves the crater in the opposite direction and, with alternating current, it opposes the rotation of the arc.

With high-power arcs (using the Beck effect) working only on direct-current, the positive carbon is horizontal with its axis in line with the optic axis; the negative carbon, set obliquely, lies at about 75° to the optic axis in order to clear the crater. It is essential always for the axes of the two carbons to be in the same vertical plane.

912. Carbons must be kept dry; the spluttering of an arc is often due to damp carbons. The heat from the rheostat or the lamp house can be utilized to dry them. They are also very brittle,

and there is risk of cracking them if they fall or are held too tightly in the carbon holder. When a copper-coated carbon is broken internally, it breaks completely in course of use at the position of the crack and must be replaced immediately. If carbons are too small in diameter to fit the carbon holder, a brass sleeve should be used to take up the slack. After the arc has been struck and not until completely cool again, neither the carbons nor the carbon holder should be handled except by means of tongs or with a thick pad of cloth which will certainly be scorched if not burned.

When striking the arc, particularly high-power arcs, set the resistance to its maximum before placing the carbons in contact or before switching on an automatically controlled arc lamp. This will avoid blowing the fuses or throwing out the circuit-breaker. The resistance can then be reduced until the arc behaves normally. Over-running the arc, by reducing the resistance may be useful when projecting a very dense positive (coloured slide or screen-plate colour photograph).

Numerous arc lamps exist which have automatic regulation but no model has yet appeared on the market which is simple and perfectly reliable. There are, however, various types of automatic lamps which allow of a very considerable reduction in the frequency and amount of the manual adjustments necessary during a single session.

Automatic regulators have been devised in which the movement of the carbons was controlled by photo-electric cells or by bimetallic strips on to which the image of the carbons is thrown (Zaffaraus, Lozier, and Jay, 1941).

The regulation of the arc requires that it be examined very frequently. This examination must be made through sight-holes fitted with red or very dark smoked glass. With a fixed installation it is possible to avoid looking at the arc, the glare of which is more serious the more frequently it is experienced, by piercing in one of the sides of the lantern a very small hole which acts as a pin-hole ($\$ 40$), and projects on the side of the room a greatly enlarged image of the arc and of the tips of the carbons. It is then an easy matter to trace on the wall (or on a sheet of card hung there if necessary) the normal position of the carbons, thus allowing the arc to be constantly watched (F. Dogilbert, 1914).

913. The voltage necessary to operate an arc and its regulating resistance is about 40 to

75 volts. The use of an arc on a direct-current circuit makes it necessary to dissipate in the resistance a large proportion of the energy consumed (about 60 to 80 per cent in a circuit at 110 volts; from 80 to 90 per cent in a 220 volt circuit). In an installation of some size, the mains current is used to drive a rotary converter (a motor coupled to a dynamo) which provides current at the required voltage.

Using an alternating current supply, it is of advantage to convert the alternating current to direct current of the voltage desired, either by means of the above-mentioned equipment or by a transformer coupled to a rectifier.

In a smaller installation, the voltage of the alternating current is reduced either by a transformer or by an auto-transformer or by using a choke which lowers the effective voltage by throwing out of phase the voltage and the current. The efficiency of the choke is lower than that of the transformer but its cost is considerably less.

914. High-pressure Mercury-vapour Lamps. Some ciné-projectors have made use of high-pressure mercury-vapour lamps and they can also be employed for still projection or enlarging. By comparison with an arc lamp, they have the advantage of needing no adjustment during use and compared with a filament lamp, they have a higher light output. The spectral composition of the light given out by these lamps renders them very unsatisfactory for the projection of colour transparencies, however.

915. The Condenser. The condensers of projectors are similar to those already described for use in enlargers. The precautions to be taken against overheating the condenser are all the more necessary, as the light sources usually employed for projection work are very much more powerful than those used in enlarging.

In some cinema projectors, compound condensers (A. Koehler, 1915; L. Lenouvel, 1922) have been used. With these an auxiliary lens projects on the gate a sharp image of the rear surface of the condenser. Such devices are not of general importance in "still" projection.

916. Slide Carriers. Slide carriers of the usual type comprise a fixed frame which is slipped under the spring platen of the carrier stage and within which a light holder for two slides can be pushed to and fro. When one of the apertures in this holder is centred on the optic axis, the other aperture is outside the carrier stage, so that slides can be put in or taken out. Stops at each end limit the travel of the holder. To

facilitate the removal of the slides, levers are usually fixed under each half of the frame, being raised on inclined planes when the respective aperture has emerged from the fixed frame. The slide is thus raised about $\frac{1}{4}$ in. in its grooves.

In some carriers, the openings of the go-and-return holder are fitted with adapters in which the slides are placed. In this way slides of various sizes, with the picture horizontal or vertical, can be shown by means of one carrier, provided a suitable assortment of adapters is available. There are also carriers with two pairs of apertures, one behind the other, e.g. for slides of the British and continental sizes. It is necessary to re-focus when using successively a front aperture and a rear one. There are also slide carriers in metal in which each of the holders is mounted on a revolving plate, so that the slide can be placed horizontally or vertically as may be required. As there is no standard for the thickness of the carrier for lantern slides, it may happen that a lecturer taking with him his own special slide carrier may find it unusable with the projector placed at his disposal. In any case it is well to take with one some slips of wood of the same thickness as the carrier in order to stop the light issuing above and beneath the carrier when the latter is used in a projector intended for larger sizes.

Mention may also be made of the magazine carrier which the lecturer loads beforehand with slides placed in the order in which it is intended to show them, and which is actuated from a distance (G. Massiot, 1909). There are also numerous automatic devices (used for advertising) by which a picture is thrown on a screen. For the small projectors used for 5×5 cm slides a similar type of carrier is common, (including magazine carriers) but these are interchangeable with the carriers for film strips on 35-mm perforated film. Film strip holders usually comprise a spool holder at the top, and a take-up spool at the bottom, together with an adjustable mechanism to advance the film one frame at a time.

917. Projection Lenses. The lenses generally used for projection work are of the Petzval type (§ 97 and Fig. 10.6), in rack mounts for focusing. Mounts are also used in which may be placed interchangeable tubes, each carrying a lens of different focal length. Allowing for losses of light due to dust suspended in the air (and sometimes to smoke) the illumination of the screen is independent of the distance between the screen and the projector subject, on the one hand, to the image being always projected of

the same size, and, on the other hand, to the lens transmitting the whole of the light issuing from the condenser. This latter condition requires that the diameter of the lens is larger the longer its focal length, and this is unfortunately not the case with lenses interchangeable in one mount, the invariable diameter $1\frac{1}{2}$ in., $2\frac{1}{2}$ in., or $2\frac{3}{4}$ in. being that usually given to a lens of medium focal length.

Owing to the light diffused by the lantern slide, the luminosity increases a little when use is successively made of lenses with a relative aperture increasingly larger beyond the size necessary to pass the beam of "directed" light, but the contrast of the image decreases. By masking the "directed" light by means of a suitably placed opaque patch, there will be seen on the screen a partly inverted image (illuminated only in the medium half-tones) formed by the diffused light, the effect being to some extent comparable to that obtained by observation in a microscope with dark-ground illumination (H. Joachim, 1933).

The requirements of cinema projection and of projection of colour slides have led some makers to produce special lenses with the same relative aperture as the Petzval lens, but better corrected, especially as regards curvature of field. In some of these lenses the distance from the focal plane to the pole of the rear glass is not more than half the focal length. The rear glass is thus quite close to the slide and can utilize the whole of the beam without the need of such a large diameter of lens.

It has been suggested (Swift, 1894) that the field of very rapid lenses be flattened by placing in the fixed frame of the slide carrier a plano-concave lens the plane surface of which is as close as possible to the slide, this lens playing the part of the field corrector of Piazz-Smith.

For projectors used in halls of very different sizes the use has been suggested of lenses constructed on the principle of variable-focus telephoto lenses (§ 108), in order to avoid having to carry a series of lenses of different focal lengths (A. Brouquier, 1901). Such an arrangement also enables the size of the pictures to be changed during one and the same lecture, and thus the demonstrator may show on a magnified scale the details of a subject after showing it as a whole.

It is easy to improvise cheaply a projection lens of large aperture, but incompletely corrected, yet nevertheless quite suitable for projection in a hall of very large size where the spectators

nearest to the screen are some yards away. To do this, two plano-convex lenses are assembled so as to form a very large "Ramsden ocular" (L. Lumière, 1924). To obtain a lens of focal length F , two identical plano-convex lenses of focal length $f = \frac{1}{2}F$ are obtained and mounted with their convex surfaces facing each other, at the ends of a tube (or box) of length equal to $8/9F$. It should be borne in mind that the nodal points of the whole lens are crossed, their separation being equal to $4/9F$.

For instance, two lenses of 56 in. focal length and 8 in. diameter, mounted at 37 in. from each other, will form a lens of 42 in. focal length working at $F/5.3$.

Testing a projection lens is best done under normal conditions of use, employing as a test plate a thin plate of metal in which holes with clear-cut edges have been pierced.

918. Cooling Devices. Until recent years, overheating of the lantern slide (or of the preparation, in cases where anatomical or other sections are directly projected) was avoided by a water trough placed in front of the condenser. This trough, the sides of which are formed of glass, contains either pure water or certain salt solutions the efficiency of which has sometimes been over-stated.

Pure water certainly absorbs the infra-red rays of great wavelength, but not those near to the visible extreme red, and both kinds produce heat only. The absorption of the infra-red can be increased only by the addition to the water of a substance of selective absorption which also absorbs some of the useful light. Alum, which is sometimes recommended, has no effect other than that of clarifying the water if it is dissolved before boiling. Glycerine also is very slightly effective except that it raises the boiling point of the water. It is obviously necessary to select a salt of which a solution of useful strength does not transmit light of a very marked colour. For instance, in troughs of about 2 in. thickness a 10 per cent solution of ferrous sulphate may be used (C. E. K. Mees, 1912; this is very easily oxidized in spite of the addition of a little sulphuric acid), or a 1.5 per cent solution of copper sulphate, which is perfectly stable, may be used (W. Crookes, 1921). It is best to use distilled water, or, failing this, water which has been boiled, to avoid the formation of lime deposits on the glass. The water trough may be connected to a tank at a higher level, so as to ensure a continuous circulation, thereby avoiding overheating, with the

consequent risk of bubbles. The water in the trough may be cooled by a coil through which cold water circulates.

It has been suggested that the light source (incandescent lamps) be immersed in a water trough (E. Borlandi, 1912) or to combine two water troughs with a slide carrier (P. Féron Vrau, 1921) for use alternately.

In cinema projectors it has been common practice for some years past to cool the film by blowing moist air against both its surfaces.

Glasses able to withstand considerable heating, and slightly tinted a greenish blue, absorb the greater part of the infra-red rays and absorb only a little light. They can themselves be cooled by having air blown on to them.

The inclusion of a heat filter such as this is now almost standard practice with miniature slide projectors. The filter is usually made from Chance ON 19 or ON 20 heat-absorbing glass.

PROJECTION SCREENS

919. General Notes. Types and Efficiency of Screens. Pictures may be projected on an opaque screen, the projector being on the same side of the screen as the spectators (projection by *reflection*), or on a translucent screen, the projector being on one side of the screen and the spectators on the other (back projection). The choice between these two methods usually turns on the nature of the premises. Where the slides are shown to assist a lecture, it is usually preferable for the projectionist to see the lecturer because he can then foresee his requirements, collaboration between the two being thereby better assured. Also, for back projection to be satisfactorily seen it is necessary that the spectators should view it from a position not far from the projection axis, so that their number is smaller than when an opaque diffusing screen is used.

For a long time the only screens used were opaque ones with a mat surface. Since 1910 screens with semi-diffusing and semi-reflecting surfaces (metallized screens: J. Anderton, 1891; A. and L. Lumière, 1901, etc.) have also been used, a very much greater luminous efficiency being sometimes claimed for them. A sheet newly coated with magnesia throws back about 90 per cent of the light it receives, and a much higher efficiency is inconceivable. The essential difference between the mat screen and the metallized screen lies in the manner in which the light is distributed by the screen. A mat screen throws it back almost uniformly in

all directions; a spectator viewing the screen at an angle almost grazing its surface sees it nearly as brightly lit as a spectator occupying a position opposite the centre of the picture. With a metallized screen, on the other hand, the major part of the light is sent back according to the laws of specular reflection; a spectator opposite the screen sees it very brightly, but as soon as a position away from the perpendicular to the screen-surface is taken, the brightness decreases, at first slowly and then with increasing rapidity, especially on that side of the screen which is farthest from the viewer. If a sheet of good-quality white blotting-paper be placed against the surface of a metallized screen by an assistant, the metallized surface will appear much brighter than the paper when one faces the screen, but the screen soon appears less bright than the latter as one moves to the side.

A metallized screen and a mat one are therefore not interchangeable. It cannot be said that one is brighter than the other. The former is better for use in a long, narrow hall of which the screen takes up nearly the whole width, whilst a mat-surfaced screen is better in a very wide hall in which the spectators in the front rows see the screen under considerable obliquity.

Between the above two extreme cases there are various intermediate types, usable within an angle of about 30 degrees on either side of the normal; screens with a rough metallic surface, metallized screens covered with a layer of small glass beads in contact, etc.

The screens in common use are of flat surface. Under the pretext of suggesting a sensation of relief or of rendering the illumination more uniform, screens of curved surface have frequently been advocated. The fact that the perception of relief in viewing an image projected on to a curved screen depends exclusively on auto-suggestion has been established by the very people who have devised such screens, for not only have they made claims for curves of the most diverse kinds, but the number of those advocating a concave surface is about equal to that of the advocates of a convex one. As regards more uniform illumination, it is no doubt correct that a screen formed of the concave portion of a cylinder with a vertical axis would be advantageous if the projection were made before a single spectator placed, as the lens of the lantern, on the axis of curvature of the cylinder, but this advantage disappears in the case of a spectator removed to any extent from this ideal position.

In public cinemas, the loud-speakers are placed behind the screen and it is necessary therefore for the screen to absorb as small a fraction as possible of the sound. This is achieved by perforating the surface of the screen with small holes, regularly spaced. They are too small to be seen and make up only 4 to 8 per cent of the surface area. The brightness of the picture is only very slightly reduced.

920. Opaque Diffusing Screens. A screen may be made on a wall by a coat of plaster (if necessary, hardened with fluosilicic acid, so as to render it washable) or by covering it with a washable mat white paint.

Usually, however, the screen needs to be of fabric mounted on a roller like a blind or stretched on a frame. This frame can be suspended from fixed pulleys by cords fitted with counterweights, or it may be one which can be taken to pieces for occasional use or transport, in which case the frame is held up for use by a folding support or one that can be taken to pieces. In this case the sheet is edged with a wide hem in which there are brass eyelets (of the kind used on tarpaulins) at about 6 in. intervals. The sheet can then be stretched by a cord which passes through the eyelets and also round the frame; or opposite rods of the frame may be passed through each of the hems, one side of the frame serving as a roller on which the sheet is wrapped when not in use, so as to avoid creases.

Although the screen has sometimes been made of American cloth, or oil-cloth, or similar coated fabrics which have the advantage of being easily washed, it is usually preferred to employ a white sheeting of close texture. Calico may be obtained up to 9 ft in width, and canvas without a join up to 24 ft. If larger than this, the screen is made of several widths, the joins being hidden by the coating. The coating to be applied (after the sheeting has been stretched on its frame in the case of a screen not intended to be removed) consists of a white, opaque material such as whitening mixed with glue, or, preferably, with the following (Molteni, 1894)—

Gum arabic	50 g
White magnesia (hydrocarbonate)	200 g
Water, about	1000 ml

A very small quantity of glycerine (10 ml) may be added to this mixture to render the coating somewhat more flexible when the sheet is rolled.

921. Metallized Screens. Three varieties of

semi-reflecting metallized screens may be listed: (a) Semi-mat screens comprising either a white, smooth, glossy surface, a rough metallized surface or, finally, a beaded surface. Whilst a mat screen may reflect 70 per cent of the incident light, the reflecting power remains constant up to about 40° from the axis. These screens, up to 30° from the axis, have a superior brightness to that of a mat screen (being almost double at the centre of the screen). (b) Semi-reflecting screens (strictly speaking) having a fine-grain metallized surface, the central brilliance of which is greater than that of the previous type but which are only of such an advantage over a relatively narrow angle. (c) Reflecting screens, made up from satin aluminium or smooth metallized card, having almost specular reflection. They are used only for amateur cinematography with low efficiency projectors or for stereoscopic projection using polarized light.

The first metallized screens were made by pasting silver paper on canvas. Subsequently such screens have been prepared by painting with aluminium, or by dusting aluminium on to a surface covered with an adhesive varnish. A metallized screen is efficient over a wider angle as its surface is less perfectly reflecting and of coarser structure (within the limits imposed by the necessity of avoiding visible granularity). For these reasons a metallized screen is sometimes sprayed over with a very thin coat of mat varnish or white paint. The suggestion has been made of producing, prior to metallization, a rough surface by coating the screen with an adhesive on which sand, crushed glass, or minute glass beads are spread. For the metallic coating, by dusting on, talc, magnesia, or even scales of boric acid, have been mixed with the aluminium powder.

On account of the marked differences in the diffusing properties of the various commercial types of metallized screens, an order for such a screen should be given only after making tests of samples, so as to judge whether the screens would be best in the particular hall where it is proposed to use them, and which is most suitable among them. The various samples are placed on a sheet of fine quality white blotting boards. An image is thrown on the composite screen thus formed. Then the extreme degree of obliquity, for a given screen, may be taken as the angle between the line of sight and the projecting beam at which the luminosity of the screen just matches the luminosity of the

white blotting card surrounding it (P. Ritter von Schrott, 1913).

As a coating use may be made of one of the aluminium paints or an aluminium cellulose varnish (preferably sprayed by an air-brush), or the following mixture (L. Lobel, 1922).

In 1,000 ml water, slightly warmed in a water-bath, mix—

Slaked lime	. . . . .	30 g
Casein	. . . . .	35 g
Sodium silicate	. . . . .	10 g

To this mixture add 20 g of whitening, and 20 g of impalpable aluminium powder.

For a permanent screen, excellent results have been obtained (C. W. Gamble, 1920) by using as a screen a sheet of glass not more than $\frac{1}{4}$ in. thick, its front surface being matted with a sand-blast, the back surface being silvered.

922. Translucent Screens. A screen for back projection may be a sheet of glass matted by sand-blasting, in the case of a fixed installation of large size, or a fine metal gauze or muslin, stretched on a frame and serving as a support for a translucent coating (gelatine, or cellulose varnish, holding in suspension a very finely-divided white substance such as alumina, barium sulphate, etc.).

An excellent screen is obtained by using tracing paper, or, better still, tracing cloth, supplied in rolls of various widths up to about 5 ft.

Various plastic materials in sheet form are now available of which one or both sides are finished with a fine-grain mat diffusing surface.

Plain (uncoated) calico may be used, but it must be wetted to increase its transparency. For this purpose a florist's syringe is generally used. To prevent the evaporation of the water during the lecture, which would entail re-spraying, the water should contain about 10 per cent of glycerine, or, cheaper, about 10 per cent of the very hygroscopic calcium chloride.

With too transparent a screen (ground glass, thin fabric tissues such as cambric or lawn, etc.) the projection lens is seen through the screen in the form of a bright spot which greatly interferes with the viewing of the picture. Also the angle within which the spectators may be placed is then very narrow.

923. Daylight Screens. Various arrangements enable pictures to be shown in full light on a translucent screen.

We must particularly mention the use, between the screen proper and the spectators, of a translucent curtain, either black or dark-coloured, so that no light other than that of the

lantern reaches the screen except the light filtered by the curtain (Isnardou, 1911). It is also possible to employ screens of translucent plastic material of somewhat dark colour, e.g. greenish-grey), the rear surface of which (turned towards the lantern) is flat, whereas the surface turned to the spectators is ribbed (J. F. R. Tröeger, 1913). The screen is placed so that it receives only a little stray light on its rear surface, at least in the direction of the spectators. We have seen satisfactory projection on such a screen in the open air in very fine weather.

THE LANTERN LECTURE

924. The Lecture Hall. When there is occasion to build or to adapt a hall for lantern work it is preferable to select a hall which is much longer than it is wide, thus enabling advantage to be taken of the metallized screens. It is obvious that the size of the screen must be in accordance with the length of the hall, but the first rows of the audience must, as far as possible, be far enough from the screen to prevent it being viewed at an angle of more than 50° (i.e. at a distance from the screen about equal to its width). If the floor of the hall is level, the lower edge of the screen must be at a greater height than is necessary with a hall built like an amphitheatre, more especially so in a long hall. If the seats are fixed, they should be staggered from row to row, thus enabling each spectator to see the screen between the heads of the two people seated in front of him. It is not necessary for the first rows to be raised in tiers; the steps need not begin until the fifteenth row. The average height of a step is 6 in. In every case it is necessary to make sure, by means of a section drawn to scale, that the arrangements will permit of everyone having a clear view of the screen.

Unless it is quite impossible, the position of the projector should be such that the optic axis of the lens cuts the screen in its centre; otherwise it is necessary to de-centre the lens (§ 906).

In many halls the screen is surrounded by a wide mat-black border, the drawbacks of which outweigh the advantages. The ideal is to surround the screen with a grey tint illuminated so that its brightness is about $\frac{1}{4}$ to $\frac{1}{5}$ that of the high-lights of the projected image and three times that of its deepest shadows.

925. The Illumination of the Hall. It is customary to put out all the lights while slides are being shown, except for some low-power lamps covered with coloured filters to indicate the exits. It is, however, possible to retain an

illumination sufficiently bright to permit of note-taking after the eyes have become accustomed to it. For this purpose only indirect lighting from the walls and ceiling must be employed, the sources of light and their diffusers being hidden from the eye. A slightly yellow light (lamps with amber filters or dipped in amber-coloured varnish) is generally best. Except for the screen, no surface exposed to the sight of the audience must have a brightness greater than 1 foot-candle. The illumination of a horizontal surface at the level of the spectators may be as much as $\frac{1}{10}$ foot-candle in the front rows, then gradually rising to $\frac{1}{4}$ foot-candle in the back rows. These limits may be exceeded if the screen is at the rear of a stage and is thus protected from the major portion of the light scattered by the ceiling and walls. The illumination of the entrance passages should be regulated so that the spectator is brought imperceptibly from the light outside to the dim light of the hall (L. A. Jones, 1920).

In the most usual case where the lighting of the hall is of either full brightness or practically nil, it is advisable that the switches should be controlled by the projectionist, so as to ensure that the lights in the hall shall not be put out or dimmed except when the first picture is about to be shown.

926. Optics of Projection—Choice of Focal Length—Size of the Projected Picture. The following two problems may arise in projection practice—

1. It is required to find the focal length of a lens covering suitably a screen of given size, the projector being at a given distance (the distance reckoned from the lens). If, for example, the picture width of the lantern slide is a maximum of 3 in. and if the width of the screen is 10 ft (120 in.), the ratio between the image on the screen and that on the slide is equal to $120/3 = 40$. Now, it is known that to enlarge an image 40 times (§ 64), the sharp image is formed at a distance from the lens equal to 41 times the focal length. If, therefore, the distance from the lens to the screen is 26 ft, the focal length of the lens for complete covering of the screen will be $26 \times 12 \div 41$ in. = 7.6 in. As a rule, it is unlikely that a lens with the exact focal length required will be available, and to be certain that the projected image will not extend beyond the screen, a lens will be chosen with the next greater focal length, e.g. one of 8 in.

2. It is required to calculate the distance (from a screen of given size) of a projector fitted

with a lens of given focal length so that the projected image may suitably cover the screen. The picture width of the slide being 3 in. (as above) and the screen measuring, say, $7\frac{1}{2}$ ft (90 in.), we get the ratio of $90/3 = 30$. The lens having a focal length of 6 in., it must be at a distance from the screen of 31 times its focal length, that is, 15 $\frac{1}{2}$ ft.

927. Communication Between Lecturer and Projectionist. In a well-conducted show there should be no occasion for the lecturer to address the projectionist. The latter should be told by signal when to begin showing the slides, when to change the picture, or when to interrupt projection. In a hall used regularly for lectures it is best to arrange two bell pushes and three wires for working two small lamps clearly visible to the projectionist. A white light, for instance, for showing a slide, and a red light for interrupting the projection. An electric bell, arranged to strike once only, or, better, a "buzzer," the sound of which is more smothered, may be used, one stroke for showing a slide and two for an interval.

Failing these various devices, it is at least possible to inform the projectionist of the different pauses in projection by placing cards, cut to the size of the slides, at the end of each series.

928. Arrangement of the Slides. The slides should be cleaned and arranged in their proper order before the lecture. Nothing is so disagreeable as the projection of finger-marks or the appearance of a picture other than the one announced. Care must be taken, when arranging the slides, to place all the same way, as indicated by the spots, these being placed uppermost, so as to be readily seen at the moment when they are taken out of the box by the projectionist.

Avoid having to ask again for a slide which has already been through the projector, as this always leads to the showing of several slides before the desired one is found, there being nothing to single it out. Subjects required twice in a lecture should be made in duplicate, or, if not, the slide should be bound with white binding strips and distinctly marked, a corresponding mark being made on a card or cover glass placed later on in the series.

When slides have been kept in a very cold room or have been carried in very cold weather, they are liable to become covered with a dew when exposed to the air of the hall. It is therefore as well to warm them by putting them in racks placed close to a heating apparatus.

929. Placing the Slides in the Carrier. As previously stated, the image can be projected on to an opaque or translucent screen.

In both cases the slide must be placed in the carrier so that the lower part of the picture is at the top, i.e. the indicator label in French and American slides must be at the top, while the spots on English slides must be at the bottom. These marks must be turned away from the lens when the screen is an opaque one, but they must be turned towards the lens when showing through a screen.

Before the lecture starts, the projectionist should satisfy himself that the slides handed to him bear the spots and that they are all placed the same way. The projectionist should always have ready gummed spots to mark slides handed him unmarked (this work is best done in consultation with the lecturer), and also pieces of gummed black paper to cover up marks which have been obviously wrongly placed. Failing numbers or other indication, he should ascertain from the lecturer which is the first slide to

be shown. The slides must then be placed at the side of or below the projector, placed on edge in a long box, if possible facing the same way as they will be in the slide carrier, so that it will be unnecessary to turn them round before placing in the carrier. If it is not possible to replace them after use in the same box without risk of confusion, another box must be provided in which they must be put as each one is taken out of the projector. A careful projectionist will return the set of slides entrusted to him in such a condition that they can be shown again without any need for rearrangement and even cleaning, the slides being never touched with the fingers except in the parts covered by the masks.

After the last slide has been shown, the lamp must be put out, but as far as possible it is necessary to avoid opening the lamp house while it is still very hot, or at least it must be closed again immediately, so as not to produce draughts of air liable to cause cracking of the condenser.

CHAPTER I

STEREOSCOPY

GENERAL CONSIDERATIONS

930. **The Sensation of Relief.** We have already seen (§ 33) that the two determining causes of the sensation of relief are the dissimilarity of the two images seen separately by the eyes and the variation in the effort of convergence of the two ocular axes. We have also seen that in

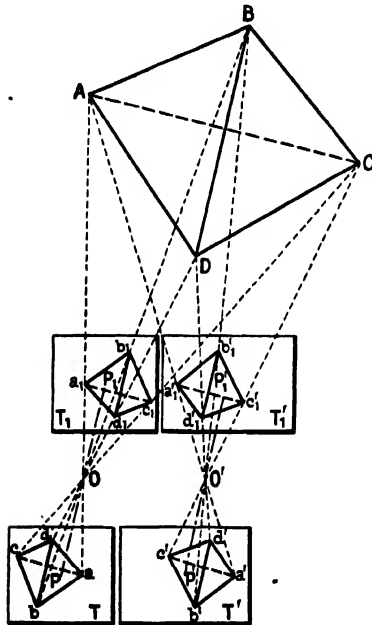


FIG. 50.1 OPTICS OF STEREOSCOPIC PHOTOGRAPHY

proper circumstances, by viewing two perspectives of the same object, the two viewpoints being a distance apart equal to the separation of the two pupils, we obtain the sensation of seeing the object in relief (stereoscopic vision). Stereoscopic relief must not be confused with the slight illusion of relief seen when examining *certain* photographs through a large diameter lens, or by reflection in a concave mirror. This illusion, due to the considerable curvature of the field of the virtual image, only occurs

when the nearer objects occupy the marginal part of the photograph (street or lane of trees viewed along its axis).

It is, however, necessary to emphasize at the outset that stereoscopic production of relief is regulated not only by geometric considerations. While these certainly play a primary part, in stereoscopic vision, more even than in binocular vision, there is also a psychical element in the process, the nature of which is imperfectly understood. When examining the same images in the same stereoscope adjusted each time for the best effect, different observers get very different impressions of the amount of the relief.

A person having eyes symmetrically placed, equal and free from aberration, can see rapidly and without effort the relief of a stereogram (two pictures corresponding to the two images as seen by the eyes placed side by side) correctly mounted and examined in a properly adjusted stereoscope. However, the adaptability of the eyes plays an essential part in the appreciation of very slight reliefs, which are often only visible after several minutes' attentive observation.

A person whose eyes are unequal or astigmatic sees relief normally if he retains for stereoscopic viewing the correcting glasses necessary for his ordinary vision. But a subject whose defects of vision cannot be corrected (diplopia, strabism, etc.) is obviously as helpless as a one-eyed individual where stereoscopic vision is concerned. At the time when stereoscopic photography was introduced into France, none of the members of the Section de Physique de l'Académie des Sciences were physiologically capable of perceiving stereoscopic relief, and the principle would have been officially condemned had not a member of l'Académie, the chemist Regnault, happily endowed with two normal eyes, intervened.

The distance between the centres of rotation of the two eyes, equal to the distance from centre to centre of the pupils when looking at a distant object, varies greatly from one individual to another, according to race, sex, and age. Its mean value is generally greater for men than women; in adults it is generally between $2\frac{1}{2}$ in.

and 3 in. (54 and 76 mm), the mean adopted being about $2\frac{1}{4}$ in. (63 to 65 mm).

931. **Stereoscopic Photographs.** Two photographs T and T' of the same object $ABCD$ (Fig. 50.1) are taken under the same conditions from two points of view OO' (separated by a distance equal to the mean inter-ocular distance) simultaneously, with two identical lenses on two plates similarly situated, or in succession after shifting the camera parallel to the plane of the plates. From the two negatives T and T' are taken two positives T_1 and T_1' , and, the eyes occupying the position previously occupied by the lenses, each positive is placed opposite the eye to which it corresponds at a distance OP_1 , $O'P_1$ equal to the principal distance OP , $O'P'$. It is necessary to give the principal points PP' a separation equal to the separation OO' of the lenses and the eyes; the image of each point is then situated on the visual ray through the point in question.

Examination of one of these photographs by the corresponding eye (the other being closed) will give, from the point of view of perspective, the same sensation as the object itself. The simultaneous examination of two images will give us the sensation of shape, size, and position which we perceive in examining the object itself, the reconstructed object being identical with the object photographed. A transparency, being of better gradation and easier to illuminate than a paper print, always gives a more perfect illusion.

932. **Limits of Perception of Binocular Relief.** An observer, viewing a point A situated in front of a plane P (Fig. 50.2) and closing alternately the two eyes, sees the point A projected alternately at a_1 and a_2 . Binocular vision shows us the point A detached from the plane P if the distance a ($= a_1a_2$) is at least equal to the limit of resolution of the eye at the distance in question.

Taking $1/2,000$ radian as the mean sharpness of vision and $2\frac{1}{4}$ in. as the mean separation of the eyes, and calling d and d' the distances of the point A and the plane P from the observer (all distances being measured in inches), from the similar triangles AO_1O_2 and Aa_1a_2 , we get

$$\frac{a}{2.5} = \frac{d' - d}{d} \quad \text{whence} \quad d = \frac{d'}{\frac{a}{2.5} + 1}$$

and since, at the limit, $a = d'/2,000$, we find

for the distance of a point A from the background P

$$d < \frac{d'}{1 + 0.0002/d'}$$

or

$$\frac{1}{d} - \frac{1}{d'} > 0.0002$$

The zone of depth $d' - d$ in front of a plane in which all objects appear to be in the plane P is sometimes termed the *neutral zone*, and the

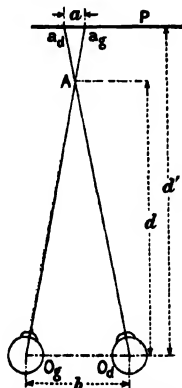


FIG. 50.2. ZONES IN BINOCULAR VIEWING

depth d , measured from the observer in which binocular relief can be appreciated, the *efficient zone*. The following table gives the depth of the efficient zones and neutral zones for various distances of background—

Distance of background. Metres	Depth of efficient zone. Metres	Depth of neutral zone. Metres
1	0.992	0.008
3	2.93	0.07
10	9.28	0.72
30	24.4	5.6
100	56.5	43.5
300	90.7	209.3
1,000	115	885
∞	130	∞

933. **Increase in Range of Stereoscopic Relief.** There are two ways of extending the limits of perception of relief and of decreasing the depth of the neutral zones.

By the use of a binocular system (binoculars, field glasses) magnifying n times one can resolve

an angle n times as small. At great distances the depth of the neutral zone is thus reduced to $1/n$ its original depth, and the sharpness of vision of relief is n times as great.

By the use of a system of mirrors mm , MM (Fig. 50.3) of the *telescope* of Helmholtz (1857), which enables an observer to use as viewpoint instead of his eyes at O_1O_2 two *virtual eyes* $O_1'O_2'$, m times as far apart, the distance between the two projections of the same point on the background (§ 932) is increased m times;

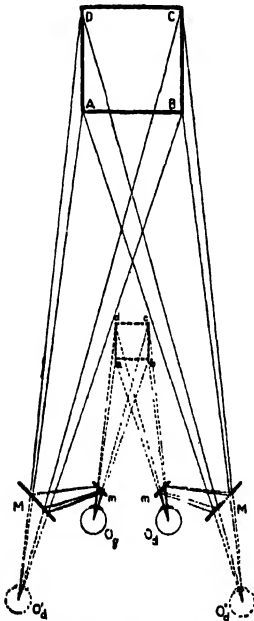


FIG. 50.3. MIRROR TELESCOPE (Helmholtz)

this reduces the depth of the neutral zone to $1/m$ of its original value and gives a power of perception of relief m times as great.

These two methods put in the place of the object examined a virtual object similar to the object itself, and situated in the efficient zone of perception of relief. In the case of the telescope the visual rays used coming from the object $ABCD$ appear to come from the object $abcd$, forming a model reduced in the ratio $1/m$ and situated at a distance from the observer equal to $1/m$ of the distance of the object in question. In prism binoculars and stereoscopic rangefinders these two methods of increasing relief are combined. The reduction

of the apparent dimensions of the object viewed is usually compensated in the rangefinder by making the magnification at least equal to the ratio of the distance apart of the objectives to the distance apart of the eyepieces.

The same means can be used to increase the intensity of relief in the examination of stereoscopic photographs and extending the range of the stereoscopic vision.

In general it would be fruitless to attempt to augment the power of separation by examining photographs under high magnification, but one can at least examine at short distance photographs taken at great distance, bearing in mind that under these conditions the reconstructed object is no longer similar to the original, but is a deformation of it (§ 29 and § 939).

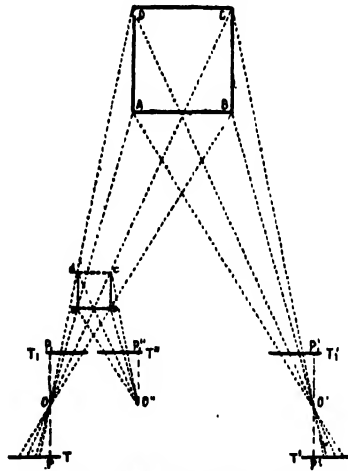


FIG. 50.4. STEREOSCOPY WITH WIDELY SEPARATED VIEWPOINTS

Increase of the *base* (distance apart of the two viewpoints or stations) is the most usual means of reproducing stereoscopically objects situated outside the range of stereoscopic vision whatever the distance of the objects from the observer may be. Stereoscopic photographs have been obtained of the satellites of Jupiter, and even of stars, with bases of enormous length obtained by using the natural displacement of viewpoint due to movement of the earth in its orbit. Bases of the order of a mile are frequently used in aerial photography at high altitude. Bases up to 100 yards are used on the earth to obtain stereograms for the construction of maps.

This process is usually known as stereoscopic photography with a large base; also under the name, incorrect in our opinion, hyperstereoscopic photography.

Take two photographs T and T' of a distant object $ABCD$ (Fig. 50.4), the camera being moved horizontally in a direction parallel to the

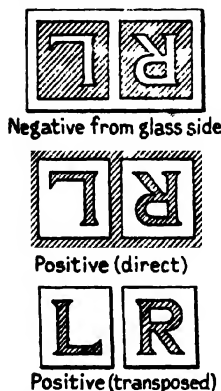


FIG. 50.5. TRANSPOSITION OF THE STEREOGRAPHIC PAIR

plate between the two exposures. The lens thus passes from the position O to the position O' such that OO' is m times the separation of the eyes. Each of the prints T_1 and T'_1 observed with one eye occupying the position of the corresponding viewpoint will give us the same sensation as that experienced in observing the object directly from the corresponding position.

Place the two photographs side by side, taking account of their orientation (left and right), and separate their principal points by a distance equal to the mean distance between the eyes; and examine the result in a stereoscope, the eyes being placed at O and O'' opposite the principal points at a distance from them equal to the principal distance. We shall then experience the same effect as we should obtain by viewing direct the object $abcd$, which is a reduced model of the object $ABCD$ in the ratio $1/m$ and situated at a distance m times as near. Photographs of this reduced model taken from the positions O and O'' would give exactly the same effect as photographs of the real object $ABCD$ taken from positions O and O' . It is easy to verify this fact by the following reasoning (G. Cordonnier, 1931): if the projections of the optic axes (in the position as when taking a photograph) be drawn on the ground, these two lines will appear at the separation of the eyes when examined stereoscopically because each of these lines occurs in the same vertical plane as the axis of the corresponding ocular; the entire landscape is clearly reduced in the same proportion.

934. Stereoscopic Transposition. In the usual practice of amateur stereoscopic photography, the two negatives of the stereoscopic pair are taken simultaneously on the same plate

in a camera fitted with two lenses and divisions.

In all cases when a stereoscopic camera utilizing a single plate is used for two successive exposures, for photographing very distant or very near objects, it is easy to register the two images in such a way that the negative does not require transposition. It is only necessary to take the left-hand view with the right-hand lens, and vice versa, the distance moved between the two exposures being thus increased by the distance between the lenses.

It can easily be seen (Figs. 50.1 and 50.5) that in order to place before each eye in its correct position the image corresponding with it, it is necessary to separate the two images, turning each through 180° to compensate for the rotation through 180° suffered by each in the camera.

Instead of cutting the positive transparency and then transposing the images, it is better to print in two stages (Fig. 50.6), printing on the right half of the plate the right-hand image which appears on the left-hand side of the negative viewed in the normal way, and then on the left half of the plate the left-hand image which appears on the right side of the negative. The name "reversing frame" by which the printing frame used in this transposition is known, and the instructions which accompany its description in some catalogues, have led some photographers to imagine that for correct vision of a stereoscopic pair one must present

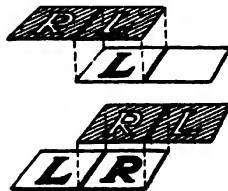


FIG. 50.6. TRANSPOSITION IN STEREOGRAPHIC PRINTING

the image formed by the right-hand lens to the left eye, and vice versa, whereas the transposition is made solely for the purpose of placing the left image before the left eye. Without this precaution, the left image would appear in front of the right eye, and vice versa.

935. Pseudoscopic Pairs. When two perspectives of a geometric solid are viewed in a stereoscope, the left perspective being presented to the right eye, and vice versa (e.g. the two drawings of a dodecahedron reproduced in Fig. 50.7), the faces which in normal vision appear

in front will appear behind (and vice versa), the reconstructed solid being thus the inverse of the original object, the reliefs appearing as hollows and the hollows as reliefs. This phenomenon is generally known as pseudoscopy.

If a pair of stereo photographs whose images have not been transposed is examined in the usual way (e.g. if the pair consists of the two images produced in a stereoscopic camera fitted with two lenses), an analogous phenomenon tends to occur, but very often the stereoscopic

point or from two points insufficiently separated relative to the distance of the object, obviously cannot give a stereoscopic effect, for there is no variation in the convergence of the optic axes when objects at different distances are examined.

When one of the negatives of a stereoscopic pair is useless, an amateur will sometimes take two prints from the good negative, making what is known as a planoscopic pair. The viewing of such a pair in the usual stereoscopic manner,

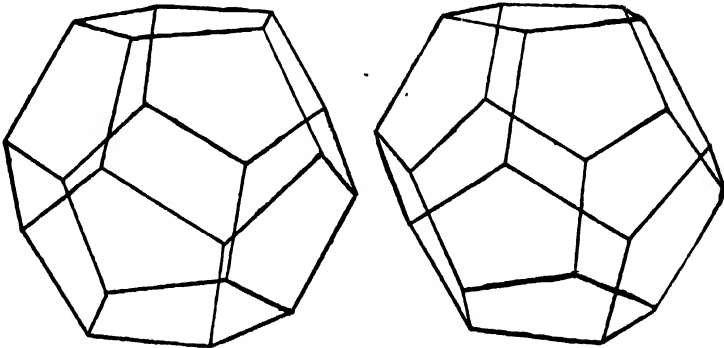


FIG. 50.7. PSEUDOSCOPIC RELIEF

effect is opposed to the perspective, and sometimes even contradicts common sense, an object partially masking another often appearing behind the object it hides.

There are, however, cases where the inversion of relief by the examination of pseudoscopic pairs affords a useful control of deductions made from stereoscopic photographs by eliminating all the effects of auto-suggestion in the perception of shape. Such is the case, for example, in radiography, where pseudoscopic vision may be used to reverse the perspectives, thus bringing the further objects to the front for examination.

If an object A is four times as far from the observer as a similar object B at the time of taking the photographs, its image will be one-fourth the size of that of B . In pseudoscopic examination A appears four times nearer than B , where it becomes four times as large as B ; as it is, on the contrary, four times smaller than B , it will appear to be sixteen times smaller than B ; the size attributed to objects varies, therefore, as the square of their distances (E. Colardeau, 1916).

936. Planoscopic Pairs. Two identical perspectives, whether taken from the same view-

each eye occupying the viewpoint of one of the images, which is merely the normal condition of monocular vision of a photograph (§ 26), often gives a certain appearance of depth; it is not comparable with the true stereoscopic effect, but sufficient to cause a planoscopic pair to pass unnoticed by an inexperienced eye in a series of stereoscopic pairs.

GEOMETRICAL CONSIDERATIONS; DEFORMATION OF THE RECONSTRUCTED OBJECT

937. Corresponding Points — Variations of Their Separation. The pairs of points appearing one in each image of a stereoscopic pair and corresponding with a single point in the object are termed homologous (corresponding) points.

Consider (Fig. 50.8) two photographs T and T' taken from two points S and S' , the optic axes SP , $S'P'$ being parallel and perpendicular to the base SS' ; the images T and T' are in the same plane, which we will assume vertical, the optic axes being then horizontal. The two images rr' of a point R at infinity appear at a distance rr' apart equal to the distance PP' of the two principal points and the distance SS' of the viewpoints.

The two corresponding points aa' of a point A at finite distance are farther apart. Draw a line through S parallel to $S'a'$, cutting the picture T in a'' ; the length aa'' represents the variation of separation of corresponding points in passing from a point at infinity to the point A in question.

Denote the length of the base SS' by b ; let F be the common principal distance of the two perspectives (equal to the focal length if the camera is focused for infinity); d is the distance from the point A to the base SS' , and e the increase of separation of the corresponding

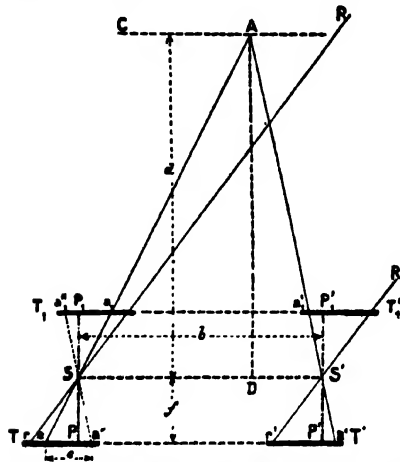


FIG. 50.8. GEOMETRY OF CORRESPONDING POINTS

points. From the similar triangles SAS' and aSa'' we get the relation $e = bF/d$; we thus see that the increase in separation of the corresponding points in passing from a point at infinity to a point at finite distance (the increase being measured on the negatives in the same position as when recording the images) is proportional to the distance apart of the viewpoints, to the principal distance, and inversely proportional to the distance d (§ 63) of the points considered. It will be noticed that the value $(b + e)$ of the separation of corresponding points is constant for all points in the plane AC , which passes through the point A and is perpendicular to the optic axes; its value will be smaller for more distant planes and greater for planes nearer the camera. Conversely, in a stereoscopic pair taken under normal conditions, all corresponding points having the same separation correspond

with points in the object situated in the same front plane.

On transposition, the differences of separation between corresponding points on the positives T_1 and T_1' retain the same values, but in the inverse sense; the nearer the object point was to the observer, the less the separation of the corresponding points, which causes the variation of convergence of the optic axes in the same sense as when the object itself is examined.

938. Parallax. The angle subtended by the base at the point A , SAS' (Fig. 50.8), is termed the parallax of the point A . Notice that there is no relation between the parallax and the separation (or variation of separation) of corresponding points. We have seen that this separation is constant for all points of the space-object in the same front plane, whilst the parallax is constant for all points of the space-object situated on the circumference of a circle drawn through the points S , A , and S' , and thus for all points on the surface generated by the rotation of the circle about the base SS' .

Considerations of parallax are of little importance in stereoscopy, and the subject is only mentioned here owing to the confusion which sometimes arises between it and the idea of separation of corresponding points in the minds of many students of the subject.

939. Deformations of the Reconstructed Object Due to the Circumstances in which the Photographs are Taken. In the various cases hitherto considered we have always assumed the images of the two perspectives to be in the same plane, and the optic axes perpendicular to this plane, and therefore parallel. Under these conditions the reconstructed object is similar to the object itself if viewed correctly in the stereoscope.

It has often been suggested that for stereoscopic photography the axes of the two lenses should converge on to the point of interest in the subject to be photographed, in the same way as the eyes converge on an object. This reasoning by analogy is unsound, since it neglects an extremely important difference between the eye and the photographic plate, the retina being approximately spherical whilst the plate is flat. The fact that the two images are generally brought into the same plane for viewing causes, on one hand, a disagreement which, in the part of the field common to the two images, prevents their stereoscopic fusion to some extent, and, on the other hand, in the parts where this fusion is possible, occasions a deformation of the reconstructed object.

It is easy to show geometrically,¹ and to verify it experimentally, that all the points on a cylinder, generated by a vertical, having for directrix the circle drawn through the two viewpoints and the point of convergence of the axes (sometimes called the *horoptic circle*) appear, when viewed stereoscopically, to be situated in a front plane. Points inside the horoptic cylinder situated on certain ellipses (or more exactly on cylinders having the ellipses for directrices) containing the two viewpoints, and having their major axes parallel to the base, appear also in front planes, as do also points outside the horoptic cylinder situated on ellipses containing the two viewpoints and having major axes perpendicular to the base; ellipses of which the curvature is greater the greater their distance from the base, appear also in front planes. Conversely, points located on front planes appear to be situated on convex cylinders of greater or less curvature according as the distance from the base is greater.

At least one case can be cited in which stereoscopic photography is only possible by a geometric method equivalent to photography with converging cameras. Stereoscopic photography of the moon is only possible owing to the *libration* of that body, i.e. a periodic oscillation exposing on each side of the mean edge a narrow strip of about 8°. The pair consists of two photographs taken at the two extreme phases of this libration. The exaggeration of relief which results from the convergence of the axes towards the centre of our satellite is compensated for (§ 940—I) by the fact that the images are always viewed at a much smaller distance than the principal distance (equal to the focal distance of the telescope used).

Another deformation occurs if the optic axes, through remaining parallel, are not perpendicular to the base; the two pictures are then not in the same plane, but in parallel planes. This condition is often produced accidentally when taking stereoscopic negatives by two successive exposures of a single camera by displacement. This does not occur if the necessary precautions are taken to ensure the correct placing of the camera in the two positions. This condition occurs frequently in aerial photography when the optic axis is not exactly vertical,

¹ The reader interested in the various deformations arising from anomalies in the circumstances in which stereoscopic pictures are taken or viewed will find a mathematical study of these deformations in *Applications de la Photographie Aérienne*, by L. F. Clerc (Paris, 1920), Part IV, Chapter V.

and the photographs are taken at the same altitude; or, if the optic axes are vertical, it may occur if the pictures are taken at different altitudes.

In this case there appear as front planes (relative to the direction of the optic axes) inclined planes, of which the inclination is equal and opposite to that of a plane drawn through the two viewpoints perpendicular to the plane which contains the optic axes (strictly, these surfaces are the surfaces of parabolic cylinders with such small curvature that they can be regarded as planes, even when extended over a considerable field).

940. Deformations of the Reconstructed Object in Stereoscopic Viewing. Various deformations arise when examining a normal stereoscopic pair under abnormal conditions. These deformations are the same as those which appear in monocular examination of a perspective when the eye is not placed at the viewpoint (§ 28), but with the sensation of a quasi-materialization of the deformed object owing to the binocular vision.

1. The most frequent deformation is that caused by viewing a stereogram with the eyes placed at a distance other than the principal distance from the photographs. The dimensions in depth then appear either compressed or extended, relative to the transverse dimensions, according as the distance of viewing is smaller or greater than the principal distance. If one considers an object whose depth is only a small fraction of the distance at which it is examined, close or distant examination increases or decreases the apparent transverse dimensions without increasing the relief; for example, a cube resting on a table with one of its faces perpendicular to the direction of vision appears as a rectangular parallelepiped with a square base when viewed at a distance other than the principal distance. The thickness of the solid thus formed is invariable, but the dimensions of the front and back faces appear greater the smaller the distance from which it is examined.

2. Assume that the eyes are placed at a distance from the stereogram equal to the principal distance, and the line joining the principal points is equal and parallel to the line joining the centres of rotation of the eyes of the observer. Assume also that the eyes do not occupy the viewpoints (decentering of the eyes relative to the stereogram). The different planes of the object thus formed slide on one another without altering their respective distances, the object thus suffering a twist such that lines of

the object perpendicular to the plane of the stereogram appear as oblique lines parallel to the lines joining each eye to the corresponding principal point. A cube photographed under the same conditions as in the preceding case will appear as a parallelepiped with square base but having four edges parallel to the direction in which the principal points are viewed. The two deformations considered above are particularly easy to obtain during a demonstration of stereoscopic projections (§ 973) or in the examination of anaglyphs (§ 951), when one moves relative to the screen or picture.

3. Much more serious deformations occur when the separation of the principal points of a stereoscopic pair is not equal to the separation of the eyes of the observer. When the examination is effected by means of an optical instrument, the principal points themselves must no longer be considered, but the principal points of the virtual images formed by the instrument used. If the separation of the eyes is greater than that of the principal points, a cube photographed as in the preceding case will appear as a species of the trunk of a pyramid seen from its larger end, and of smaller depth than the actual cube. Conversely, if the separation of the eyes is smaller than that of the principal points, the reconstructed solid will be a kind of pyramid trunk seen from its smaller end and of greater depth than the cube. In both cases the scale of depth is affected; an object plane drawn half way between the front and the back face will appear, in the first case, nearer the back face, and, in the second case, nearer the front face.

The three deformations which we have considered can be understood by imagining the visual rays to be replaced by elastic thread, so that in registering the elementary perspectives and in viewing the pair these threads are all the time attached to every point of the perspectives, and follow the eyes of the observer in all positions.

It is obvious that several conditions of viewing a stereoscopic pair may be violated at once; the resulting deformation is the sum of the elementary deformations.

941. Consider a stereoscopic pair viewed under the correct conditions, and suppose each image turned through the same angle about its principal point. If the reliefs of the reconstructed objects are feeble relative to the distance of the object itself, stereoscopic vision remains possible, but the relief diminishes more and more until it vanishes at a rotation of 90° .

After this, it gives a pseudoscopic effect of increasing intensity until a rotation of 180° is obtained; the same phenomena then repeat themselves in inverse order.

Such anomalies obviously cannot occur in subjects where vertical lines appear, but every precaution must be taken to avoid it in the case where there is nothing to give a sense of depth in one of the pictures by itself; this is often the case in various scientific or technical applications (aerial photographs taken vertically, astronomical subjects, photographs of fossils, anatomical preparations, photo-micrography, etc.).

942. Range of Stereoscopic Vision. By reason of the aberrations of the lens and the grain of the photographic image, the values previously calculated (§ 932) for the range of direct binocular vision cannot be used in the case of stereoscopic photographs taken from a base equal to the separation of the eyes. The values calculated for the extent of the effective zones are the maxima, whilst those for the extent of the neutral zone are the minima.

In the most favourable circumstances the range of stereoscopic photography is not as much as 80 yd. When using objectives of short focal length and rapid emulsions with pronounced grain, the stereoscopic range sometimes does not exceed 16 yd. This is why it is usual, in stereoscopic photography of landscapes, to include in the field a near object serving to enhance the sensation of relief, in the manner of a material foreground in a diorama.

These ranges are obviously very different when the base is smaller or larger than the separation of the eyes. If, for example, a pair taken from the two extremities of a base of length B with a principal distance F is examined at a distance f from the pair (or with eyepieces of focal length f), variation of separation between the pairs of corresponding points of two objects situated respectively at distances d and d' is

$$e - e' = BF \left(\frac{1}{d} - \frac{1}{d'} \right)$$

so that, for corresponding points of the reconstructed solid to appear at different distances, it is sufficient that the variation $(e - e')$ is greater or equal to the limit of separation $f/2,000$, then

$$\frac{1}{d} - \frac{1}{d'} \geq \frac{f}{2000BF}$$

or

$$d < \frac{BF}{\frac{f}{2000} + \frac{BF}{d'}}$$

Taking, for example, the values

$$f = 10 \text{ cm} \quad F = 50 \text{ cm} \quad B = 200 \text{ m}$$

we find as range 2,000 kilometres and as depth of the neutral zone 2 metres to 2,000 metres, or 0.5 metres to 1,000 metres. The value $F/2,000$, chosen arbitrarily for the resolving power of the plate, would correspond here to the separation of images less than $\frac{1}{1000}$ in., a condition only realized with slow plates, such as are used in map surveying by stereoscopic methods from stations on the ground.

It will be noticed that if the distance from the background remains the same, the extent of the neutral zone is constant if, all other conditions remaining the same, the product BF of the base and the principal distance is a constant. To obtain at different distances d' stereograms of the same power (same extent of neutral zone) the product BF must be varied proportionally to the square of the distance d' .

943. Normal and Exaggerated Relief. The relief perceived in the viewing of the stereogram of a very distant object or an object of microscopic size is often said to be exaggerated. But without this exaggeration it would be useless; our eyes would not be able to perceive the relief of a distant range of mountains, or of the ground as seen from an aeroplane, or of a microscopic preparation.

An object a , m times as small as an object A , and situated m times as near, gives a sensation of relief m times as great, and it is here that the large bases become useful in stereoscopy.

If it is correct to say that, under certain conditions, the sensation of relief is much more pronounced; it is not correct to speak of exaggerated relief when the reconstructed object is similar to the object itself, the stereogram being viewed under normal conditions.

One should avoid as far as possible the use of the expression *exact relief*. If under certain conditions we can obtain a stereogram which, correctly viewed, suggests perfect similarity between a relatively thin object and its image, objects situated nearer or farther from the observer will not give this sensation of similarity; the relief will be increased for near objects, and weakened for distant objects. We know, besides this, that the stereoscopic sensation varies from one individual to another.

THE EXAMINATION OF STEREOGRAMS: STEREOSCOPES

944. Viewing Stereograms with the Naked Eye. By making the axes of the eye diverge,

some people can view normal stereoscopic pairs with the naked eye, provided the distance between the principal points is little different from the separation of the eyes. Such viewing is made easier by holding a piece of cardboard between the two pictures perpendicular to their common plane.

It is generally easier by squinting, so that the axes of the eyes converge, to see in relief a pair which, when viewed normally, has the characteristics of a pseudoscopic pair, the left perspective being on the right, and vice versa.

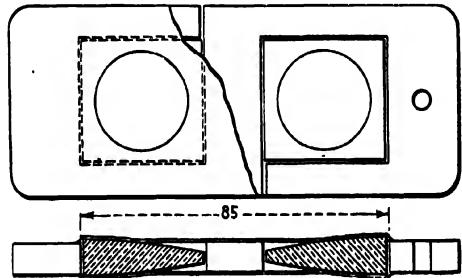


FIG. 50.9. STEREOSCOPE BINOCULAR
(Buguet)

This kind of viewing is made easier by holding a mask at some distance from the eyes, only allowing one eye to see the single image which corresponds to it (Elliott and Waterston, 1857).

For example, to view at about 10 in., the two perspectives of the regular dodecahedron reproduced in Fig. 50.7 (M. Miet, 1921) one must hold at about 4 in. from the eyes a card with an opening of about $1\frac{1}{2}$ in. square. Owing to the convergence of the ocular axes, the reconstructed solid appears to be situated practically half way between the plane of the pair and the eyes. This object appears much smaller than either of the images viewed from the same point with monocular vision, after removing the mask.

Examined with a binocular stereoscope (Fig. 50.9), this same drawing appears to be a dodecahedron, but not regular, in which the near faces will be those which appeared farthest when examined with the naked eye.

Remember, however, that the viewing of a stereogram with the naked eye by divergence or convergence of the ocular axes is a great strain, so that it is impossible to make a complete study of a series of stereograms or to examine more than a few at a time. These two methods of

viewing were suggested by Wheatstone (1838), who, in the first case, recommended the use of two tubes directed towards the principal points of a stereogram, the separation of these points being reduced.

945. **Stereoscopes with Convergent Eyepieces.** Most of the stereoscopes used for amateur

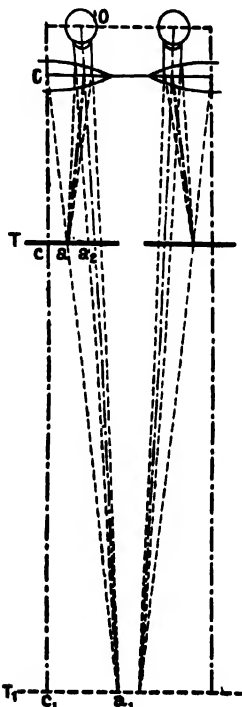


FIG. 50.10. PATH OF RAYS IN BUGUET BINOCULAR STEREOSCOPE

stereoscopy and for some scientific and technical applications are derived from the prismatic lens stereoscope of Sir David Brewster (1844). In its original form this instrument used as eyepieces two convergent lenses having their centres outside the centres of the two eyes (often reduced to two half-lenses), the separation of the centres being about 25 per cent greater than the separation of the eyes. Under these conditions one can view without fatigue a stereogram in which the separation of the principal points is about 15 per cent greater than the separation of the eyes, and may thus reach about 3 in. If the virtual image given by each of the eyepieces

were always at infinity, the adjustment being made instinctively by an observer with normal eyesight, the separation of the principal points would equal the separation of the ocular axes. A "binocular stereoscope" is represented in Fig. 50.9 (A. Buguet, 1891). This is the simplest form of stereoscope, useful for examining stereograms printed in a book or periodical. In Fig. 50.10 the paths of the rays are indicated in such a stereoscope, for the case of a near point of the reconstructed object (the ocular axes are convergent).

The eccentricity of the eyepieces increases the inevitable aberrations met with in the use of uncorrected or partially corrected lenses, the more so since the lenses must be of the shortest focal lengths compatible with covering the wide angle of the field; and the shorter the focus the greater the aberrations due to the eccentricity of the eyepieces. It is therefore an advantage to have a stereoscope in which the separation of the eyepieces can be adjusted.

Some years ago cameras giving images farther apart than the mean separation of the eyes were almost completely abandoned in amateur stereoscopy. Under these conditions the separation of the principal points is equal to the mean separation of the eyes, and the eyepieces can generally be centred relative to the eyes. However, individuals having eyes abnormally close together require the eyepieces farther apart than those adjusted for eyes having a separation at least equal to the mean. Further, an observer unaccustomed to stereoscopic viewing can accommodate his eyes more easily to eyepieces having a greater separation than those which will suit him, after he has had some practice in stereoscopic viewing. For these two reasons stereoscopes are to be preferred which include the means of regulating the separation of the eyepieces, besides the usual power of making the images coincide.

It is not unusual that a person unaccustomed to stereoscopy, to whom you give a stereoscope not adjusted to his eyes nor to the separation of his pupils, declares after a few seconds that he sees much better by closing one eye, his attempts to adjust the eyepiece having been haphazard. To adjust a stereoscope one must first adjust the focus by closing one eye for an instant, and then, with both eyes open, adjust the screw governing the separation of the eyepieces (by a rod carrying a thread cut so as to move each eyepiece in the opposite direction) until the two images coincide without the least effort of convergence of the eyes.

These trials are usually avoided if the separation of the eyepieces is made about $\frac{1}{2}$ in. greater than the separation of the eyes. Stereoscopes intended for the use of unaccustomed observers may be graduated to indicate the separation of the eyepieces.

We cannot go into all the variations met with in practice, and must refer the reader to the catalogues. However, we may mention the stereoscope in conical box form, which is excellent for viewing transparencies and, by adjusting a movable shutter fitted with a mirror, also for the viewing of stereograms on paper. Interesting effects may be obtained by removing the ground glass used as diffuser, which forms the back of the stereoscope, and using a diffusing reflector, e.g. plates of mat metal, tinted papers, etc. (G. Cromer, 1919). There are also the simplified stereoscopes used for paper prints, automatic stereoscopes with metal frames for the pictures mounted on endless chains (of which some models do not function until a coin is placed in the slot), stereoscopes for films run from one spool to another, and the cabinet stereoscopes with interchangeable magazines (made about 1900) in which one picture is substituted for another by pressing a lever.

946. Complementary Stereoscope. The essential condition for the reconstructed object being identical with the objects itself is that each of the images is seen at a distance equal to the principal distance, or at least by means of an eyepiece of focal distance equal to this principal distance (§ 28). The focal length of the eyepieces is not marked on stereoscopes; it may be found with reasonable accuracy (especially when the eyepieces consist of achromatic plano-convex systems having the convex side facing the images) by using the stereoscope as a camera to focus a distant object on its ground glass screen; the focal length is then the distance from the pole of the eyepiece to the screen. When one restricts oneself to the photography of distant objects, the principal distance is practically equal to the focal length of the objectives used to take the photographs, and the above condition is then satisfied if the eyepieces of the stereoscope have the same focal length as the objectives of the camera; it is said then that the stereoscope is complementary to the camera used. Placing a stereogram in a complementary stereoscope, and placing oneself at the actual viewpoint, one eye looking into the stereoscope and the other looking directly at the view, the two images are very nearly

of the same dimensions, and can usually be combined.

The general practice in stereoscopy is to fit the camera with lenses of very short focal length, and it is sometimes difficult to fit the stereoscope with such short-focus eyepieces, owing to their higher cost. The greater curvature of such lenses compels the use of a smaller number at once; the field is limited owing to the considerable thickness of the edges, and also to the distortion of the marginal regions. Thus the eyepieces of stereoscopes are frequently of

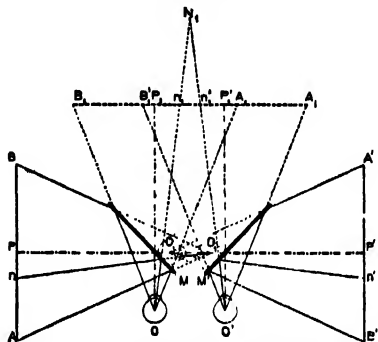


FIG. 50.11. WHEATSTONE STEREOSCOPE

greater focal length than the camera lenses, resulting in exaggeration of the foreground and deformation of the reconstructed object, and tending to give the effect of theatre scenery in successive planes.

When the difference of focal length is not considerable one can often add an auxiliary lens (§ 117) to each eyepiece of the stereoscope, the power necessary being the difference of powers (§§ 63 and 70) of the camera lens and stereoscope lens. In like manner a stereoscope having lenses of too short focus can be corrected by means of a divergent auxiliary lens. Meniscus lenses of diameter equal to the stereoscope lenses are chosen for preference, and are introduced into the mounts. They are kept out of contact with the stereoscope eyepieces by means of cardboard rings of sufficient thickness, and placed next to the eyes with their convex faces outwards (C. Schitz, 1914).

947. Stereoscopes Using Symmetrically-placed Mirrors. The stereoscope of C. Wheatstone (1838) employed only two mirrors, M and M' (Fig. 50.11) at right angles, and placed at 45° to the direction of vision. The two photographs constituting the pair are represented by AB ,

$A'B'$, parallel to the plane bisecting the two mirrors. Under these conditions the eyes O and O' see at A_1B_1 and $A'_1B'_1$, the reversed images of AB and $A'B'$, two homologous points n and n' being seen respectively at M_1 and M'_1 and giving thus the illusion of a point N_1 of the reconstructed object at the intersection of the rays On_1 and $O'n'_1$. The necessity of using reversed images has somewhat reduced its popularity, in

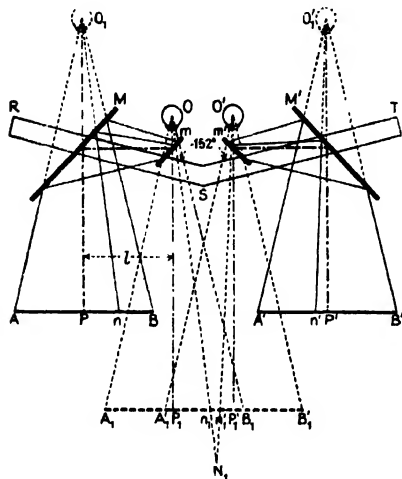


FIG. 50.12. TWO-MIRROR STEREOSCOPE
(Cazes)

spite of the fact that there are no limits to the size of the photographs which may be viewed.

Inspired by the telestereoscope of Helmholtz (§ 933), L. Cazes (1895) made a stereoscope using two pairs of mirrors, mm' , MM' (Fig. 50.12), for viewing stereograms of large size having the pictures placed side by side in the same plane. The "virtual" eyes $O_1O'_1$ are brought each time opposite the principal points PP' (their separation may vary from 5 in. to 20 in.) by sliding the mirrors MM' on rails RST (graduations on the rails enable one to make sure the mirrors are symmetrically placed). The whole instrument is carried on an extensible vertical column to ensure equality between the distances O_1P , O'_1P' , and the principal distances of the perspectives (up to 25 in.). Converging or diverging lenses may be placed in front of the eye mirrors, to regulate the apparent distance of the foreground, according to a table on the instrument. The effort of accommodation imposed on the eyes is then equal to the effort of convergence

when viewing the object direct. The geographical service of the French army (1923) worked out a combination of this stereoscope with a prism binocular, for examining aerial stereograms, giving a magnification of about 3.5. Combinations of one or other of these types of mirror stereoscopes with light boxes (negatoscopes) are used for examining stereoscopic radiographs.

There is also, of this type, the stereoscope of C. Pulfrich (1904), carrying in front of each eye a prism of quadrilateral section, of which two adjoining faces reflect successively the pictures to be examined. The pictures are inclined at an angle of about 120° , their planes intersecting behind the observer.

948. Stereoscopes Having Two Reflectors in Front of One Eye. It is clear that one of the images of a stereoscopic pair can be viewed with the naked eye, and the other after reflection in two parallel mirrors suitably placed to enable fusion of the two images. This fusion is only possible on the condition that the path of the rays between the two reflecting surfaces is negligible compared with the distance of the stereogram from the eyes. Such instruments have been designed, notably by J. Duboscq (1857), for viewing two images placed one above the other, and by T. Brown (1895) for viewing two images side by side. On the same principle, F. Drouin (1896) has proposed the use of prisms of quadrilateral section (totally reflecting the light from two opposite faces), to be held in front of one eye for examining normal stereoscopic pairs or pseudoscopic pairs (not transposed). Such instruments have been used at various times for viewing stereoscopic projections.

949. One-mirror Stereoscopes. L. Pigeon (1904) made an instrument, somewhat analogous to the one described in 1849 by Brewster and in 1851 by H. W. Dove. Closed, this instrument appears like a book; when opened, the two side panels form an angle of about 140° ; a median frame joined to the sides by linen or metal strips bisects the angle formed by the side panels. On one of the panels is placed at $A'B'$ (Fig. 50.13) a normal image of the right-hand picture, and on the other panel at AB is placed a reversed image of the left-hand picture. The two pictures can be joined by means of a paper or cloth hinge; the whole slides under a bridge in the lower edge of the bisecting panel. A small mirror M is fixed at the end of the bisecting panel DM in such a position that the left eye O can be placed very

near to it; this eye sees at A_1B_1 the reflected image of AB , whilst the right eye O' sees $A'B'$ directly.

A curious case of stereoscopic viewing, using only a single reflection, is that of the "cube" of H. Swan (1863) in which one appears to see a person or a head and shoulders on a very small scale. Two small rectangular glass prisms having an angle of 40° are fastened together by their hypotenuses, but *without cementing*. The left eye placed facing one of the large faces sees directly the left-hand picture cemented to the opposite face, whilst the right eye, placed obliquely, only sees (by total internal reflection) the right-hand picture, which is stuck, after reversal of the image, on the side face of the prism, under the condition that the field of vision is very limited. The pictures are therefore very small.

50. Stereoscopes with Reversing Prisms. Many devices have been worked out to produce a stereoscope for viewing stereograms printed without transposition from a pair taken on a single plate. Unfortunately, their use has not become general, but the principles employed will be briefly indicated.

A stereoscope suggested by Brewster in 1849 has two mirrors back to back in a plane perpendicular to that of the pictures examined, and situated half-way between the principal points. Each eye then sees the reversed image of its picture. The same inventor pointed out the possibility of reversing the images by means of a direct-vision total-reflecting prism in front of each eye.

The stereogram can be placed above or below the eyes and seen by means of a mirror held in front of the eyes (T. Brown, 1899), or placed in a plane parallel to the plane containing the two axes of vision, and seen by reflections at 45° (G. Balmittère, 1909). In another model by the latter inventor the stereogram is placed in a vertical plane at about 45° to the axes of the eyepieces; two reflectors suitably placed produce virtual images normal to the direction of vision. The inequality in the two optical paths is then compensated by placing in the path of the more distant image a prism of appropriate thickness or an eyepiece constructed differently from that in the other path.

Stereoscopes with reversing eyepieces comprising total-reflecting prisms were worked out by Duboscq (1857) and by E. Colardeau (1911); in this model the prisms, producing three reflections, are placed between the eyepieces and the

transparency to be examined; they are held in a movable carrier which can be removed from the field to allow of pseudoscopic examination of the same stereogram, or stereoscopic viewing of a transposed stereogram.

951. Anaglyphs. An anaglyph consists of the two pictures of a stereoscopic couple superimposed on the same support, the two pictures being printed in two complementary colours.

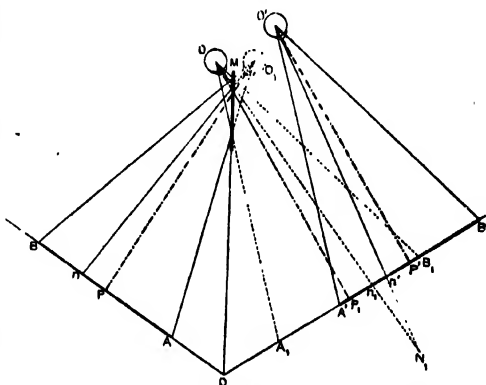


FIG. 50.13. SINGLE-MIRROR STEREOSCOPE
(Pigeon)

The result, though meaningless to the naked eye, appears in relief if examined through a double eyepiece such that each eye sees through a filter of colour complementary to the colour of its corresponding image (L. Ducos du Hauron, 1891).

The priority of Ducos du Hauron has been questioned owing to some geometric drawings made by W. Rollmann (1853) in two complementary colours (yellow and blue). But the two images of the pair were side by side as in ordinary stereograms and not superimposed; their dimensions were thus limited to the separation of the eyes.

The left-hand image is generally printed in blue-green or bluish-green, and the right-hand image in red, slightly orange. Under these conditions the left eye through a red filter sees the green image in black on a red ground, and cannot see the red image on this red ground; it therefore sees only its corresponding image. In the same way, the right eye through a green filter sees the red image in black on a green ground and cannot see the green image (or only very feebly).

Whilst red dyes and pigments may be obtained

of very great purity of colour, transmitting or diffusing almost all the red light from the complex incident light, blue, blue-green, and green dyes and pigments always consist of blended tints (§ 6) reflecting or diffusing only a fraction of the radiations not absorbed, and consequently appearing grey when viewed through a filter of the same colour.

The reconstructed object therefore appears black on a ground of colour not far removed from the tint resulting from the mixture of coloured lights transmitted respectively by the two filters, but with momentary predominance of one colour or the other, according to the state of fatigue of the eyes.

When examining these anaglyphs with the two-colour eyepieces, those parts of the object the corresponding points of which are printed in coincidence appear to be in the plane of the anaglyph, the other elements of the reconstructed object appearing in front or behind this plane. The elements whose corresponding points have a separation equal to (or slightly smaller for easy viewing) the separation of the eyes will appear at infinity.

Anaglyphs have several advantages: they do not impose any limit to the dimensions of the pictures and only require for examination an instrument very easily and cheaply made by means of coloured gelatine or plastic-sheet filters (manufactured on a large scale) fixed in a light card, which can be punched out. After falling into disuse soon after their invention, anaglyphs have been employed to illustrate some scientific publications, and since 1923 have received many applications (projections, catalogues, illustrated journals), the prints usually being made by a photo-mechanical process. Notable applications of anaglyphs have been made to anatomy (M. d'Halluin, 1908), to geometry (H. Richard, 1912), to geographical and geological maps (H. Hubert, 1917), to astronomy (L. Gimpel and E. Touchet, 1924).

952. Vectographs. Another printing method similar to the anaglyph, but which eliminates the use of coloured images (which causes a certain amount of eye-strain), is the Vectograph, invented by E. H. Land in 1938. In this case each image is produced in a material which polarizes the light in proportion to the density of the image. The plane of polarization of each is at 45° to the vertical, one on either side. Hence, when viewed through a pair of polarizing filters similarly orientated, each eye is

enabled to see its own image but not the other, provided each picture is correctly printed with the appropriate orientation. The images are deep violet-brown and appear the same colour through each eyepiece.

The printing is carried out by means of a special Vectograph (non-light-sensitive) film which is coated on each side with a transparent material having very long chain molecules, which are orientated during coating so that they lie at 45° on either side of the vertical. They are not birefringent in the raw state.

A gelatine matrix is made from each stereo negative, one reversed from left to right, and the two matrices are superimposed face-to-face. They are then soaked in a Vectograph solution which is taken up by the gelatine. A sheet of the Vectograph film is then slipped between them and the sandwich passed through rollers. The solution in the two images then has the effect of making each surface of the Vectograph film polarizing image-wise, the plane of polarization being determined by the direction of coating of the film. After stripping away the matrices, which can be used repeatedly, the combined image can be viewed by transmitted light or, if lacquered on the back with an aluminium layer, as a print. Polarizing filters for viewing can be made from sheet Polaroid, held in cardboard frames.

953. Parallax Stereograms. Imagine in front of a plate P (Fig. 50.14) in a parallel plane a grating T formed by opaque vertical and transparent bands, having the same width l over the entire length of the grid. Place at two points O_1, O_2 separated by a distance b (mean separation of the eyes) and at a distance d from the plate, the two lenses fitted with reflectors for reversing each image and at the time of recording the images adjust the separation e between the grating and the plate to satisfy the relation $e = \frac{dl}{b}$. Under these conditions the bands

$GG'G'' \dots$ of the sensitive plate only receive light from the lens O_1 , whilst the intermediate bands $DD'D'' \dots$ only receive light from the lens O_2 . The sensitive plate can thus only register half the total area of each of the images of the stereoscopic pair, but, if the bands are sufficiently narrow (about 125 to the inch), the discontinuity of each image will not be as conspicuous as the discontinuity of photo-mechanical reproductions (see for example the plates in Chapter XVII, obtained by means of cross-line screens of about 150 lines per inch).

After taking the photograph, the plate is developed and reversed and placed in the same position relative to the grating, the eyes of the observer being placed at O_p and O_s . Each eye will then only see the bands of image corresponding with it, and the observer will see the object in relief, without the use of any viewing instrument, since the grating is attached to the stereogram and is thus part of it.

This stereoscopic process, suggested in 1896 by A. Berthier, was put into practice by F. E. Ives in 1903, and perfected in 1906 by E. Estanave. These two authors have pointed out many other applications of the same principle, notably "auto-stereograms" in colour on Autochrome plates (1907), the ordinary or stereoscopic changing pictures (1910), which show successively two distinct images, or two or three attitudes of the same person, by moving the picture relative to the observer (*living portraits*).

As in the case of anaglyphs, the elements of the object registered in coincidence appear in the plane of the stereogram, the other elements appearing either in front or behind, according to the relative positions of their corresponding points.

In practice, "parallax-stereograms" are not taken directly, as we have said, but printed successively from the negatives of an ordinary stereoscopic pair, the grating only being used in the reproduction by means of a triple-body camera; between the copying of the two pictures the lens is moved through a distance equal to the separation of the eyes, perpendicularly to the bands of the grating.

It may be noted that if the observer places the right eye at O_p and the left eye in the symmetrical position of O_s relative to O_p , he will see a pseudoscopic image. It would be the same for an observer correctly placed relative to the image if the grating were displaced through a distance equal to the width of the open bands. In all intermediate positions, or if the observer is not at the required distance from the stereogram, each eye sees a little of each of the images, and the result is very confusing.

954. Integral Photography. Under the name of integral photography, G. Lippmann in 1908 suggested a method the embodiment of which in practice was attempted in 1925 by E. Estanave.

A celluloid sheet of convenient thickness is embossed on its two faces with a large number of hemispherical projections, in such a way that the converging system formed by each element

of the celluloid face when facing the subject gives an image on the emulsion covering the opposite hemispherical element. Without the use of any other optical system (except a mirror for the optical reversal of the image which is necessary, although not included in the original description), one obtains a very large number of minute images of the subject opposite which the film is exposed. After development, reversal, washing, and drying, the film examined from any viewpoint will show a complete image of the subject photographed, each point of the

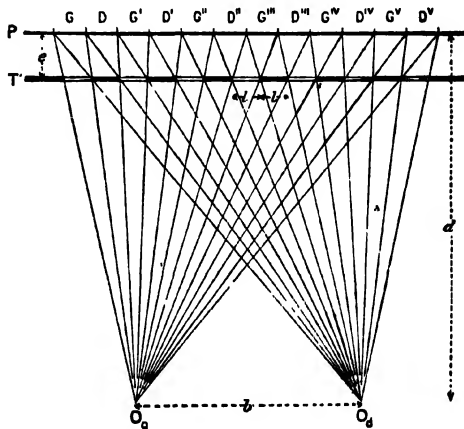


FIG. 50.14. PARALLAX STEREOGRAM

image (or, at least, each small element—almost a point) being supplied by one of the elementary images. Binocular vision of this gives the stereoscopic effect, with this peculiarity, that as the observer moves in front of the system, parts of the reconstructed object become masked and then unmasked by other parts, just as they would in moving about in front of the object itself, whereas in viewing a stereoscopic pair it is always the same objects in the background which are masked by the objects in the foreground, whatever the deformation of the reconstructed object, as the eyes are moved in front of the pair.

Prompted by this principle and by the parallax stereograms, C. W. Kanolt (1918) then G. Bessière (1925) and J. de Lassus St. Geniès (1932) have produced some very curious photographs, which, seen from almost any viewpoints, give a perfect stereoscopic sensation with relative displacements of the objects situated at various distances when the observer moved from side to side.

To obtain these peri-stereoscopic photographs the sensitive plate can be exposed, for example, a certain distance behind a vertical grating (the openings being $1/400$ in. wide and the lines $1/64$ in. wide). The lens, fitted with a reversing prism and a diaphragm in the form of a vertical slit, is given a sideways movement during exposure (in the case of same-size reproduction) or a rotation about an axis situated behind the plate when reproducing on a reduced scale, the position of the sharp image being just behind the plane of the plate. The plate thus records behind each opening of the grating, which acts as an elongated pinhole, a complete image of the object, retaining the vertical dimensions but compressing considerably the transverse dimensions. The lens only plays a small part in the formation of these anamorphoses, obtained in such a way that each point of the object corresponds to a single point in each elementary image. Once the negative is obtained, as many prints may be taken as are desired, and these are viewed by fixing a grating in front of them identical with the one used in making the negative.

955. Photo-stereo-synthesis. In spite of the fact that photo-stereo-synthesis (L. Lunière, 1920) does not involve any stereoscopic principles, the powerful sensation of relief given merits their inclusion among the various methods of stereoscopic photography.

The subject (generally a head and shoulders portrait) is photographed six times in such a way that the focus of each image is confined to a single plane of the subject. This limiting depth of the field is obtained by suitable calculated movements of the lens and plate relative to the subject during the exposure of each negative. The camera is moved nearer to the subject after each exposure, so that a new "section" is recorded on the same scale of reproduction. The six negatives thus obtained are printed very lightly on transparency plates (the sum of the six densities only just making up the density of a normal transparency). These plates are superimposed, their thicknesses representing (on the scale of the image) the thickness of each of the sections of the subject. The whole is illuminated from behind by a diffusing screen, and, on viewing from the one possible position, a sensation of relief is obtained, the part of each image in focus being the only effective part as far as the eyes are concerned.

This method has been applied with success to photomicrography (F. Bastin, 1921) and to radiography (E. Pohl, 1930).

TAKING STEREOSCOPIC NEGATIVES

956. Usual Stereoscopic Sizes. Stereoscopic apparatus, consisting of two coupled cameras, usually form the two images of the pair on a single plate or film. Formerly some cameras used two separate plates, automatically marked by an inscription on one of the images made by a cut in the shape of a figure in the frame limiting the extent of the picture. The usual size of the first stereoscopic transparencies was 85×170 mm (approximately $3\frac{1}{2} \times 6\frac{3}{4}$ in.), the two joined images each measuring about 75×75 mm (3×3 in.), with lateral margins of 10 mm ($\frac{3}{8}$ in.), corresponding to the position of the binding and title. These transparencies were printed from negatives taken on plates 8×16 cm (approximately $3\frac{1}{8} \times 6\frac{1}{4}$ in.) or 9×18 cm ($3\frac{1}{2} \times 7$ in.).

The International Congress of Photography held at Brussels in 1891 recommended the same size, 85×170 mm, with single images 66×70 mm ($2\frac{5}{8} \times 2\frac{7}{8}$ in.), separated by a band of width 4 mm ($\frac{1}{4}$ in.), leaving thus a distance of 70 mm ($2\frac{3}{4}$ in.) between the principal points. This recommendation was never used in practice, and was changed by the Congress held at Brussels in 1910, where it was decided to allow "all sizes which can be held in a frame formed by two squares of side 80 mm ($3\frac{1}{8}$ in.), placed side by side, it being assumed that homologous points of an object at infinity must not, under any circumstances, be more than 80 mm ($3\frac{1}{8}$ in.) apart, and that a smaller distance is preferable."

However, negatives and transparencies of the same size are now usually used, the single images being very nearly square. The stereoscopic camera cannot be turned through a right angle for taking "vertical" and "horizontal" pictures; square images are therefore chosen to give the best results in both cases. Vertical and horizontal pictures may be obtained by masking the square negatives or by making suitable enlargements. The sizes most frequently used in stereoscopic cameras are given in the following table—

Nominal external size	Approximate dimensions of each picture	Space between the two images	Separation of principal points
7×13 cm ($2\frac{7}{8} \times 5\frac{1}{8}$ in.)	64×60 mm ($2\frac{5}{8} \times 2\frac{3}{8}$ in.)	4 mm ($\frac{1}{4}$ in.)	65 mm ($2\frac{5}{8}$ in.)
6×13 cm ($2\frac{3}{8} \times 5\frac{1}{8}$ in.)	54×60 mm ($2\frac{1}{8} \times 2\frac{3}{8}$ in.)	4 mm ($\frac{1}{4}$ in.)	65 mm ($2\frac{5}{8}$ in.)
4.5×10.7 cm ($1\frac{7}{8} \times 4\frac{1}{8}$ in.)	39×42 mm ($1\frac{5}{8} \times 1\frac{7}{8}$ in.)	20 mm ($\frac{3}{4}$ in.)	63 mm ($2\frac{3}{8}$ in.)

There are also excellent cameras of 9×12 cm and 10×15 cm, generally fitted with three lenses, two for stereoscopic work and the other of longer focal length for a single image on the whole of the plate. Recently, some cameras have been made for miniature stereophotography (using 35-mm perforated film), giving pictures 24×36 mm or 24×24 mm. In some cases a film-transport mechanism is provided which enables the negative pairs to be interspersed so that, in spite of the wide separation of the pairs of negatives, no film is wasted and yet no negatives overlap.

The adoption of 35-mm film as a sensitive material has the great advantage that the integral tripack colour films which are plentiful in this size can be used. Since these films are usually processed to a transparency direct, no printing is involved. In the case of one stereoscopic camera available in the U.S.A. a complete kit is manufactured, to go with the camera, which enables the transparencies to be bound up with the minimum difficulty and viewed in a stereoscope of excellent design.

957. Stereoscopic Cameras Having Two Lenses. Stereoscopic cameras made to take the two stereoscopic photographs simultaneously are usually hand cameras of as varied designs as ordinary cameras (Chap. XIV), and are fitted with the same accessories. However, for scientific or commercial applications of stereoscopy, hand cameras or studio cameras can be used if they are fitted with a separating "partition" similar to the bellows, fixed to two rods engaged in notches at the front and back of the camera, the partition being held on both sides by elastic fastenings to the ends of the rods.

Since stereoscopes are not fitted with means for decentring the eyepieces, if one wishes the reconstructed object to be geometrically similar to the object itself the camera lenses used in making the negatives must never be decentred. It is to reduce the need of such decentring that lenses of very short focal length are frequently used. As, however, the negatives of a stereoscopic pair are often used separately for printing, enlarging, or projecting, that is to say, when decentring is of some importance, manufacturers make a compromise by fitting their cameras with a vertical movement of small range. Some makers of simple cameras, who, on account of price, cannot use wide-angle lenses, consider that, for the majority of amateurs, conditions of geometric similarity are secondary to the

advantages of decentring. Whereas, in ordinary photography, it is rarely necessary to ensure that the principal point corresponds to the horizon, their cameras are fitted with the lenses raised above the centre; if the photographer wishes to work from a high viewpoint he can use the camera upside down, thus getting a lowering of the lenses. The stereoscope corresponding to such a camera must obviously have its lenses decentred by the same amount.

The two lenses of a stereoscopic camera must be identical, so that they produce images in focus of the same dimensions and luminous intensity at the same distance.

Trouble would inevitably occur if the various adjustments were made on each lens separately: the focusing mechanism and the iris diaphragm are coupled by means of rods, except in the particular case when the separation of the lenses can be controlled.

The use of two separate shutters is avoided for the same reason, apart from the fact that they would be more expensive than a stereoscopic shutter with two openings. An American stereoscopic camera of the reflex type is fitted with a reversing stereoscope for viewing the images in relief on the ground glass, as suggested by F. Drouin (1893).

958. Stereoscopic Cameras Avoiding the Need for Transposing the Negatives. The production of stereoscopic images capable of being viewed directly in an ordinary stereoscope by reversal of the original images is a problem whose solution has been sought from the beginning of stereoscopic photography on Daguerreotype plates. It was solved by A. Claudet (1853) by fitting each of the lenses with a mirror or prism for optical reversal of each image.

Many attempts have been made since then to bring this type of camera into every-day use, notably those of J. Carpentier (1895), by means of right-angled prisms placed between the front and back components of the lens; by J. A. Tournier (1902), by means of reflectors inside the camera, projecting the images on to a roll-film wound round the partition separating the two dark compartments; and by A. Daubresse (1902), by means of two reflectors inside the camera, throwing the images on a sensitive film placed between the lenses.

In spite of the advantage of such a camera in stereoscopic colour photography, there being no need to cut the negatives, it has never been popular. Note should be made, however, of the double-prism devices sold for certain

miniature cameras which enable the one lens to be used to take two stereo negatives side-by-side on the same frame, though merging together slightly in the centre. The system is similar to that mentioned in § 959, though the miniature film can be processed by reversal and examined by means of a special viewer.

959. Cameras Fitted with Mirrors for Registering Simultaneously the Two Stereoscopic Images, Using Only One Lens. In a camera taking pictures at least $3\frac{1}{2} \times 4\frac{1}{2}$ in., by a suitable arrangement of mirrors in front of the lens, two separate images may be formed of the view as seen from the position of the images of the two half-apertures of the lens in the two mirrors.

Such a duplicating arrangement, consisting of two mirrors making a very obtuse angle with one another and having their joining line vertical and situated on the axis of the lens, was devised in 1853 by F. A. P. Barnard for stereoscopic photographs on Daguerreotype plates. Each of the two images of the pair is turned round by a single reflection of the incident rays. If used to obtain negatives to be finally printed by contact, this arrangement is open to the objection that the images are reversed as regards right and left.

A duplicating system, using two pairs of mirrors, recalling the stereoscope of Cazes (§ 947), was made in 1894 by T. Brown. Each of the images being reflected twice, the negative obtained is similar to an ordinary stereoscopic negative.

The mirrors of these duplicating systems are very delicate, since they require to be silvered on the surface to avoid the double reflections obtained with an ordinary mirror silvered on the back. Moreover, these mirrors reflect at most 90 per cent of the incident light (or 80 per cent after two reflections). Also the lens forms each image with only half its surface, thus reducing its "speed" to one-half its normal value.

These arrangements are not at all suitable if one wishes to conform to the best geometric conditions; the two half-pencils which are incident on the lens only have common regions if the two axes (virtual) are convergent.

960. Stands for Two Exposures in Rapid Succession. For stereoscopic photography of inanimate objects by means of two successive exposures with any camera, a number of arrangements have been put forward which may be fixed to a tripod and automatically ensure parallelism between the optic axes in the two positions and the desired separation between the two view-points.

The following arrangements, among others,

have been used. A board with stops indicating the two positions of the camera; a board with a carriage running on guides between fixed or adjustable stops, the camera being fixed to the carriage; a board to which is secured by means of four movable rods another board, the rods and boards forming two parallelograms; this ensures parallelism in the extreme positions of the movable board.

961. Stereoscopic Photography, Using a Large Base. There are two cases to be considered: the study of a distant object of small depth, but no objects situated at intermediate distances, and the photography to the best advantage of a group of objects situated at all distances from the base and partially obscuring each other from view. As typical examples of the two respective cases may be mentioned: (i) vertical stereoscopic photography, from an aeroplane flying at great altitude, of an expanse of country, or the plan of a works, and (ii) the stereoscopic photography of a landscape from ground stations.

In all cases the camera must be of slightly greater size than the size of the images required, so that they may be trimmed to avoid any errors of orientation. When extreme accuracy is not necessary (otherwise the camera must be mounted as a theodolite), the parallelism of the two positions of the optic axis is obtained with sufficient approximation by observing the image of some object at infinity and bringing it to the same point on the ground glass, or on a reference mark on the finder (replaced, if necessary, by a telescope with cross wires, or by a rifle sight).

To avoid displacement of the clouds in a landscape by wind between the two exposures, giving the illusion of clouds nearer than the landscape, it is best to take the first photograph from the side from which the wind comes, and to reach the other station, previously decided upon, as quickly as possible.

When photographing in sunny weather from two stations successively with an appreciable interval of time intervening, the displacement of the shadows that occurs between the two exposures gives, on stereoscopic examination, the sensation of black surfaces rising above the ground as their distance increases from the object projecting them. To prevent this it has been suggested that the first station taken should be the one which, relative to the other, is in the direction of the sun.

These two recommendations may, however, prove incompatible.

962. Considering the first case mentioned

above, if we are to place the eyes opposite the principal points of the pair—the condition necessary to avoid distortion of the reconstructed object (§ 940)—the separation of the two stations must be chosen so that it bears the same relation to the mean distance of the object as the separation of the eyes bears to the principal distance (L. P. Clerc, 1917). In other words, if B is the length of the base (distance between the two stations), D the mean distance of the object from the base, b the separation of the eyes, and d the principal distance of the images of the pair (practically equal to the focal lengths of the lenses in the case of a distant object), the length

B must be chosen to satisfy the relation $\frac{B}{D} = \frac{b}{d}$.

It is for this reason that stereoscopic pairs taken vertically from the air are given a separation equal to a quarter of the altitude if the lens used has a focal length of about 10 in., i.e. four times the separation of the eyes.

963. The rule given above is obviously useless in the case of a group of objects of considerable depth; we can no longer talk about the distance of the object, as it varies considerably from one part to another.

If a series of photographs are taken of open country from a high terrace, the camera being moved at right angles to the direction of vision between each exposure, thus obtaining stereoscopic pairs of increasing separation from, say, 9 in. to 10 yd, the sensation of relief obtained in viewing the various stereograms obtained becomes more and more marked as the base is increased. But, when the stations are more than a certain distance apart, it becomes more and more difficult to make the foregrounds of the images coincide. If the base is increased still further, fusion of the images becomes impossible even in the distance, the eyes being attracted by the discordance of the foreground, however hard the observer may try to neglect it.

In determining the separation of the stations, both the distance of the foreground and the more remote parts of the subject must be taken into account. It is easily seen that for a certain distance of remote parts the base can be made larger the greater the distance of the foreground, with consequent greater relief in the remote parts.

The relation the foreground bears to the distant parts greatly influences the length of base it is possible to use. For instance, in a photograph taken from a cliff over a valley, the various object planes range in increasing distances up to the horizon or to the limit of the

remote part without any object in the foreground masking an object in the distance. Under these conditions, if the result is examined stereoscopically, the eyes can view successively the various planes, and are not influenced by quite a considerable variation of separation of corresponding points. If, on the contrary, the photograph is taken, from the ground level, of a bush or tree at about 20 yd from the camera, standing out against a hillside which forms a background, the maximum variation of separation of corresponding points appears between adjacent points.

Experience shows that in the case of a stereoscopic pair taken looking down on the subject, the eyes can stand a separation of homologous points about five times as great as in the case of horizontal views.

Most observers can endure a variation of separation of homologous points equal to 1/10 of the distance at which they are examined in the case of bird's-eye views, and of 1/50 of this distance in the case of horizontal views.

If a stereogram is viewed under normal conditions, the eyes occupying the respective viewpoints of the two perspectives, the viewing distance is equal to the focal length F of the lens used in taking the photographs, and if the foreground and distance are respectively at distances D and D' from the base, the maximum separation B of the stations is given by the following equations¹—

$$\text{Bird's-eye views } B = \frac{DD'}{10(D'-D)}$$

$$\text{Horizontal views } B = \frac{DD'}{50(D'-D)}$$

We thus obtain by other means, in the case of horizontal views, the rule given in 1895 by L. Cazes.

Frequently when one does not wish to make the reconstructed object exactly similar to the object itself, the stereoscope used for viewing has eyepieces of focal length f differing from the focal lengths of the camera lenses used in taking the photographs (photographs taken by means of a telephoto lens, and viewed in a stereoscope of short focus). In such cases the

¹ The variation of separation $s - s'$ of the homologous points (§ 937) is actually equal to

$$s - s' = BF \left(\frac{1}{D} - \frac{1}{D'} \right) \quad \text{or} \quad B = \frac{(s - s') DD'}{F(D' - D)}$$

If then $(s - s')$ is given the value $F/10$ or $F/50$ it is easily seen (L. P. Clerc, 1917) that

$$B = \frac{DD'}{10(D' - D)} \quad \text{or} \quad B = \frac{DD'}{50(D' - D)}$$

variation of separation of corresponding points must be reduced to the focal distance f of the eyepieces, and the equations giving the maximum separation of the stations become—

$$\text{Bird's-eye views } B = \frac{f}{10F} \frac{DD'}{(D' - D)}$$

$$\text{Horizontal views } B = \frac{f}{50F} \frac{DD'}{(D' - D)}$$

For example, in the case of a bird's-eye panorama in which the foreground is 2 kilometres away and the background 10 kilometres, the photographs being taken with a lens of 26 cm focal length, and examined with eyepieces of 12 cm focal length, the separation of the stations can reach 115 metres,¹ in which case the extent of the neutral zones, calculated as in § 942, have the following values according to the distance of the background—

Distance at	10,000	5000	2500 metres
Corresponding extent of neutral zone	196	50	12 metres

In the case of a horizontal view in which the foreground is situated at 20 metres and the background at 10 kilometres, the photographs being taken with the same lenses and viewed with the same eyepieces as in the previous example, the separation of the stations must not exceed 4.86 m,² the neutral zones assuming considerable dimensions.

Distance at	10,000	5000	2500 metres
Corresponding extent of neutral zone	3225	962	266 metres

The advantage of choosing a high station to eliminate any near foreground is therefore obvious.

In the special case when the view extends to the horizon, $1/D' = 0$, and the equations become respectively

$$B = \frac{fD}{10F} \text{ and } B = \frac{fD}{50F}$$

964. Stereoscopic Photography of Small Objects. If the reconstructed object is to be exactly similar to the object itself, the first condition to observe is to choose the focal length F of the taking lens and the magnification n such that the principal distance $F(n + 1)$ of the perspectives is equal to the focal length of the eyepieces of the viewing stereoscope. This

$$^1 B = \frac{0.12}{10 \times 0.26} \times \frac{2000 \times 10,000}{8000} = \frac{3000}{26} = 115 \text{ m.}$$

$$^2 B = \frac{0.12}{50 \times 0.26} = \frac{20 \times 10,000}{9880} = \frac{4800}{988} = 4.86 \text{ m.}$$

condition is often neglected. In order to photograph small objects same size by means of a camera not having sufficient extension, the two lenses may be used for taking each perspective, one acting as an auxiliary lens. This lens coupling can be effected by means of a cylindrical sleeve sliding freely on the lens hoods.

When one attempts, by means of a two-lens camera, to take stereoscopic photographs of near objects, as one approaches the objects their images on the ground glass separate and finally go out of the field. One is then forced to reduce the separation of the lenses, which is possible only with some special cameras, and is then limited by the nearness of the object. This can be done with a camera made to the design of W. Scheffer (1907) for stereoscopic photography of insects and other natural history preparations on any scale (same size). The separation of the lenses was automatically controlled by the movement of the lens carrier, which moved for focusing in such a way that the separation of the lenses was inversely proportional to the extension. Two exposures, can, of course, be taken, moving the camera a suitable distance between them (or, sometimes more simply, by giving a shift of equal amplitude to the object itself).

965. When the depth of the object photographed is only a small fraction of its distance from the lens, and when the stereogram is to be viewed under normal conditions (the eyes occupying the points of view of the two perspectives), the separation of the positions of the lens can be obtained by applying the rule given in § 962 for long-distance stereoscopy. If the photographs are taken on the scale of $1/n$ with objectives of focal length F , thus having a principal distance equal to $F(n + 1)$, if the stereogram is viewed with eyepieces having a focal length f , approximate compensation of the abnormal circumstances of viewing is obtained if the separation of the two photographing points is made equal to B , where—

$$B = \frac{2.5(n + 1)F}{nf}$$

all measurements being made in inches.

We have had occasion to verify this rule experimentally in taking a series of stereograms at increasing separations of a map in relief. More than a hundred people who viewed these stereograms and compared them with the original relief chose, as the one most like the original, the stereogram taken with a separation

of stations equal to that calculated from the above formula.

In particular, if the object is photographed natural size, the separation of the lenses must be equal to the mean separation of the eyes. It will also be necessary to view the stereogram with eyepieces of at least 10 in. focal length (which means that for perfect reproduction the object must be photographed at this same distance from the lenses), the eyes being unable to converge on a nearer point without fatigue. Further, an ordinary stereoscopic camera cannot be used under these conditions, as it forms an image of only half the object in each field. One is therefore often led, in same-size stereoscopic photography of small objects of little depth, to reduce the separation of the lenses, thus sacrificing the similarity between object and reproduced object, or to make the optic axes converge towards the object in order to bring the two images to the centres of the two halves of the plate, although this causes serious deformations in the case of an object of appreciable thickness (§ 939). It is therefore necessary, at the same time as the axes are made to converge (exaggerated relief), to reduce the separation of the two positions (reducing relief and thus partially compensating for the effect of the convergence of the axes).

The same result is obtained by rotating the object between exposures about a vertical axis cutting the optic axis, remembering to turn the source of light through the same angle about the same axis to avoid differences of illumination in the two photographs. Generally the total amplitude of this rotation is about 2° to 4° according to the distance of the object from the base.

It is worthy of note that the use of prism attachments mounted on the lenses of a stereoscope camera has been suggested, so as to ensure convergence of the axes, thus permitting relatively near objects to be photographed.

The general rule is applied much more easily in the case of objects photographed on an enlarged scale; for example, to obtain stereograms representing an object of small depth under a magnification of 10 times, no difficulties present themselves either in the taking or viewing provided one moves either the camera or object parallel to itself between exposures a distance equal to $1/10$ the separation of the eyes, i.e. $\frac{1}{10}$ in.

966. For small objects of appreciable thickness, the best results are obtained by applying

the formula given in § 963 for horizontal views, but replacing the focal distance F by the principal distance.

For example, suppose we photograph an object 2 cm deep with a lens of 12 cm focal length placed in front of a perfectly uniform background not located in the stereoscopic viewing. The middle plane of the object is focused under conditions giving a magnification of 3 times. The extra-nodal distance of the plane focused on is thus 16 cm—15 and 17 cm for the distances of front and rear planes—while the extra-nodal distance of the sensitive plate, i.e. the principal distance, is 48 cm. The optimum separation of the two positions is then given by—

$$B = \frac{12}{50 \times 48} \times \frac{15 \times 17}{(17 - 15)} = \frac{255}{400} = 0.64 \text{ cm}$$

The camera or object is therefore to be moved 6.4 mm between the two exposures.

PRINTING AND MOUNTING STEREOGRAMS

967. Masking the Pictures. An important factor in the mounting of stereograms is the choice of suitable frames (masks, trimming, or windows limiting the field in the case of stereoscopes of box form). The frames of the two elements of a pair must be equal; under these conditions they are seen stereoscopically as rectangles located in space.

If the stereogram represents a landscape, a monument, or any other object of large dimensions, the frames should be placed in such positions relative to the photograph that they give the illusion of seeing the object through a window. The distance between corresponding sides of the two frames must be about $1/25$ in. less than the separation of corresponding points of the foreground. In other words, as in looking through a window, one must see a little more of the right of the subject with the left eye, and a little more of the left of the subject with the right eye.

On the other hand, if the stereogram represents some small object against a background, e.g. a medal resting on a mount, it is desirable to locate the frame in the plane of the background, the object then appearing in front of the frame, the corresponding sides of which must have a separation equal to that of corresponding points of the background.

In order to be able to effect these localizations it is necessary to know the dimensions and relative positions of the openings of the stereoscope

to be used (small variations of this type occur between stereoscopes of different makes). To find this, a card of considerable length and about $1/25$ in. narrower than the smaller dimension of the normal size (59 mm, for example, for a stereoscope 6×13 cm) is placed in the grooves; on this card are traced in pencil the boundaries of the openings of the stereoscope and the length of card necessary for mounting prints, allowing about $1/8$ in. extra to catch hold of. It is well also to mark the boundaries of a plate of the corresponding size (Fig. 50.15).

968. Printing. The stereoscopic effect is more realistic when viewing transparencies than when viewing prints, and the former are more popular for private collections. Stereograms on glossy

difference of density scarcely affects stereoscopic viewing, though matched densities are preferable where practicable. At one time, when papers of different gradations were not available, some workers adjusted the exposures of the two prints so that one of them showed the light tones to best advantage and the other the shadows.

Since the sensation of relief results from small differences of position of corresponding points of the two pictures, any circumstances affecting the sharpness of the prints will impair the degree of relief. It is therefore necessary in printing transparencies by contact to take all the precautions recommended in § 708.

Poor lighting, under-printing, and excessive contrast in reproduction all give poor results. The "snow effect" produced by large areas of insufficient density may be mitigated to some extent by tinting the entire print, e.g. very light yellow, to give the effect of sunshine.

969. Printing Stereoscopic Transparencies. When printing in large numbers, it is usual to make a negative allowing both images to be printed at the same time, either by cutting and reassembling the original negative or by making a dupli-

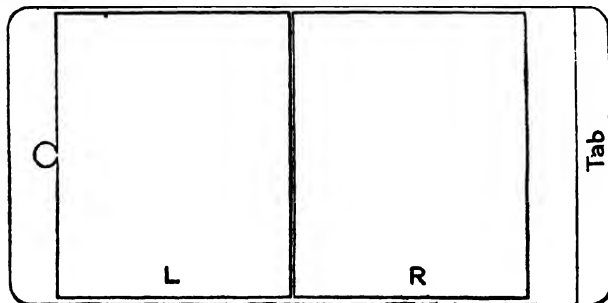


FIG. 50.15. GUIDE FOR THE MOUNTING OF STEREOSCOPIC PRINTS

paper are often used for collections of scientific or technical interest when cost is a primary consideration. Moreover, they lend themselves to transport by post, etc., with greater safety.

When dealing with large sizes only, stereograms printed on paper are practicable, and the printing is often done by photo-mechanical processes. Collotype, with its irregular grain, is generally preferable to half-tone, with its pronounced geometrical pattern. In printing stereoscopic pairs in half-tone, it is advantageous to arrange the two directions of the screen at 30° to one another, and so render the pattern less obvious.

The two images of each pair being generally exposed separately and developed together, it is necessary to take precautions to give equal exposures to the two prints. When, however, the same transparency is to be used alternately for stereoscopic viewing and projection, it is advantageous to give the image to be used for projection a little less density (by shorter exposure) than the other; even a marked

cate negative from a suitable positive.

For printing in small numbers the transposition may be done automatically by means of a triple-body camera fitted with a centre partition and two lenses (A. Bertsch, 1860), each of which reproduces one of the images of the pair and reverses it laterally, thus compensating for the reversal in the taking camera. Various devices have been made to adapt the stereoscopic camera to this purpose. In the specially constructed instruments the two lenses are generally mounted with a means of varying the separation, so as to allow of suitable placing of the images on the positive plate, this adjustment being done by examining the projected negative image on the ground glass.

A stereoscopic pair giving only a very slight effect of relief, owing to the choice of a base too short in comparison with the distance of the subject, may be considerably improved by enlargement provided there is no near foreground. A rigorous geometrical reconstruction is not, however, obtained.

The printing of stereoscopic transparencies is, however, usually done by contact in a transposing frame requiring two exposures. These frames comprise an exposure opening and grooves in which to slide the negative and positive plate. Stops hold the two plates in the positions indicated in Fig. 50.16 the left-hand image then being printed on the left half of the positive plate and the right-hand image on the right half of the plate.

The types of transposing frames usually found on the market are made for average results, and satisfy most requirements. To produce transparencies adapted exactly to a certain stereoscope it is necessary to obtain an adjustable transposing frame, or to make a suitable one. Their construction is easy if the principles given below are observed (A. Marteau, 1902).

For a long time it was usual to bind up transparencies by a piece of plain glass after the manner of lantern slides, first masking and titling the subject. The introduction of automatic stereoscopes and the popularity of small sizes, which would be much reduced by binding, has led to the abandonment of this procedure; the title is usually written in ink on one of the transparent parts (margin, or gap between the two images). It is, however, advisable to protect the film of the transparency with varnish.

970. Construction of a Transposing Frame. Procure three sheets of Bristol board which, suitably cut, are placed one on top of the other in a printing frame of convenient size, and form the transposing frame represented in Fig. 50.16. The figure is drawn practically to scale for the case of a 6×13 cm negative to be printed on to a 7×13 cm transparency plate. If the negative is of greater dimensions than the positive plate, the top card, forming the guide, will only be fixed to the others along one of the longer sides so that it may be lifted for inserting the negative. Cut out of the cards three equal rectangles of length greater (by about $2\frac{1}{2}$ in.) than twice the length of the positive plates to be used, and of width greater than the width of the plates, by about 4 in. Draw carefully the two axes xx' , yy' of the rectangles from which measurements of the various apertures will be taken.

The centre card (represented by vertical shading) is sandwiched between the other two, and its thickness must be at most equal to the thinnest negative to be printed; if not, it will

prevent contact between the negative and positive plate. In this card cut an opening $abcd$ to receive the negatives with the least possible play.

The card $abcd$, Fig. 50.16, which after mounting will be in contact with the glass of the printing frame, serves as a mask. In it cut two openings $efgh$, $ijkl$; this card must be very thin; stout paper may be used instead of card. If the individual negative pictures are larger than the openings in the frame of the stereoscope, these masks are cut about $1/25$ in. larger all round than the stereoscope masks, so that the openings are well filled by the pictures. If, on the other hand, the printing is done from a negative of smaller size, this mask is cut, leaving openings about $1/25$ in. less in each dimension than the

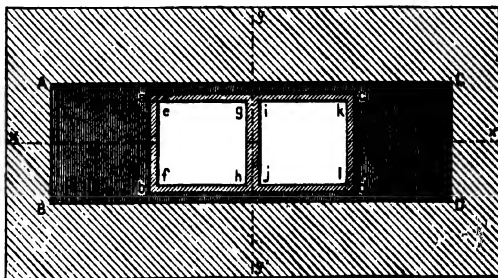


FIG. 50.16. STEREOSCOPIC TRANSPOSING FRAME

card forming the plate holder. In like manner, it will be necessary to provide each transparency with a mask cutting off the plain glass at the margin, or at least to fit the stereoscope with a temporary mask.

The distance of ef from ab is measured on several negatives, and then the opening $efgh$ cut accordingly. To carry out the recommendation made in § 967 for landscapes and large subjects, the distance between the corresponding sides ef , ij of the two openings of the mask must be about $1/25$ in. *greater* than the distance between corresponding points of the foreground as measured on several negatives (greater, not smaller, as in the finished stereogram, by reason of the transposition). This fixes the position of the second opening $ijkl$ equal to $efgh$, its horizontal sides being exact continuations of those of $efgh$. The card forming the negative holder is then glued, or fixed by any other appropriate means, to the masking card.

To make the best of stereoscopic negatives which, by mistake, were taken with an inclined base (camera tilted laterally during exposure),

a similar transposing frame may be made. The negative holder, instead of being fixed, is cut in two, and the two halves centred on the openings of the mask such that the lines joining corresponding points are horizontal, the negative being temporarily fixed by gummed strips.

The cutting of the opening *ABCD* in the upper card (represented by the spaced shading), which forms the slide for the positive plate, is best done by laying on it the card already made (Fig. 50.15) and tracing the position of the openings of the stereoscope (§ 59). To do this, the guide card is placed on the frame so that the rectangle *D* is centred over the opening *ijkl* and a trace of the guide on the negative carrier is made, thus determining the side *CD* of the necessary opening in the upper card and the beginnings of the sides *AC* and *BD*. The side *AB* will be fixed by the condition that the distances of *cd* from *CD* and *ab* from *AB* must be equal. It only remains to cut this third card on which has been drawn the rectangle *ABCD*, and to glue it on the other two in the position indicated by the lines.

971. Stereoscopic Prints on Paper. Stereoscopic prints are best trimmed with the help of a trimming plate cut from the glass of a waste negative of size about $1/25$ in. greater than that of the opening of the stereoscope.¹ When the print is taken from a pair of negatives on a single plate, the horizontal sides are cut first with a trimming plate of sufficient length and of width slightly greater than the height of the openings of the stereoscope, on which a squared pattern has been traced, having one direction parallel to the length of the stereogram. These lines may be made by drawing on an undeveloped fixed plate. It is then easy, if the camera was correctly levelled when taking the views, to make the cuts correspond to the vertical lines of the subject (monuments, interiors) and to the horizontal lines joining corresponding points of the pictures (in the case of photographs taken with an inclined camera, the two pictures had best be trimmed separately). The trimming of the vertical sides is then done with a plate slightly wider than the openings of the stereoscope. It is convenient to have this plate marked with numbered vertical lines facilitating its adjustment. In order that the framing should play the part of a window for the foreground, the plate is placed with one of

the vertical lines on an easily identified reference point in the foreground of the left-hand picture, and the plate is next placed on the right-hand picture, so that the corresponding reference point is on the right of the vertical ruling.

Before trimming, take care to mark the two prints with a soft pencil on their backs with the letters *L* and *R* to avoid confusion when mounting. If this precaution has been omitted the two prints may be identified as follows. Lay one print on top of the other and hold them up to the sun or a powerful source of light, their emulsion sides facing the observer. Adjust them until the backgrounds coincide; then the foreground of the left-hand picture extends beyond the right of that of the right-hand picture.

The positions of each of the prints on the mount are marked with a slip of card or thin metal on which has been drawn or traced the transverse boundaries based on the guide card (Fig. 50.15), but remembering that the width of the prints should be slightly greater than that of the openings of the stereoscope. It is very important, before finally attaching the prints to the mounts, to make sure that the lines joining corresponding points are parallel to the long sides of the card. This can easily be verified by means of the trimming plate already used for cutting the horizontal sides.

For rapid mounting, the wet prints may be applied gelatine side down to a piece of glass the same size as the transparencies. To obtain the correct positions the glass is placed on the guide card (Fig. 50.15). The prints being seen through their backs, the left-hand image will be on the right, so that when seen through the glass the two occupy their correct positions.

972. When the photographs have been taken on separate plates, and particularly in the case of large negatives taken from two distant stations, it is first necessary to identify them as already described. If it is desired to make the reconstructed object appear in front of the frame, the two prints can be trimmed simultaneously by making their backgrounds coincide while trimming. Otherwise, trimming in this position must be limited to the horizontal sides, the vertical sides being cut as described above. In the case of vertical aerial photographs, consideration of the displacements of the backgrounds and foregrounds is not sufficient to differentiate the two photographs. The left-hand picture is generally the one of which the

¹ For mounting photographs smaller than the size for which the stereoscope is intended it is best to use black or very dark cards. The card may obviously be of any colour if it does not appear in the field of view.

principal point is nearest to the left-hand side (except in the case of views taken with axes accidentally converging to a point above the ground). In this case horizontal cuts must be made parallel to the line joining the respective principal points of the two images.

We cannot go into all the special precautions necessary in mounting stereoscopic prints of large size for mirror stereoscopes; these precautions will suggest themselves after some experiments with the particular stereoscope to be used. The procedure will be understood from what has already been said.

973. Stereoscopic Transparencies from Separate Negatives. If the negatives have been taken with a stereoscopic camera using two separate plates, it is easy to construct a transposing frame similar to that described in § 970, but, in place of the single negative carrier *abcd*, two separate negative carriers must be made, sufficiently separated from one another to give the necessary rigidity to the card situated between the two openings. This increases the separation between the openings and the length of the slide *ABCD* for the positive plate.

For printing large stereoscopic pairs on a single transparency such a transposing frame would be very cumbersome. Moreover, when the negatives have been taken from separate stations, the backgrounds do not generally appear in the same position on the two negatives, and such a transposing frame can only be used for pairs of negatives whose backgrounds are in the same position relative to the openings.

The following method (L. P. Clerc, 1917) works very well. Two card frames (Fig. 50.17), not thicker than the thinnest positive plate, are cut with openings of the normal size of the positive plates. The two frames are marked with the letters L and R, and also by means of notches which are cut on the two sides of the marked corner so that the plates can be lifted.

A stereoscopic pair, printed on paper from the desired negatives is mounted on a sheet of glass of the same dimensions as the transparencies, the prints being attached to the glass by their backs. Before the mountant is dry this provisional stereogram is viewed in the stereoscope to make sure it is mounted correctly.

After drying this model, the right-hand negative is applied against the print, in a good light, and the two right-hand images caused to coincide. If, owing to stretching of the paper, coincidence cannot be obtained over the whole image, adjustment is made over the central

region. Register having been obtained, it is carefully maintained, and the whole placed on the edge of a table, the negative underneath. Now pass the left hand through the opening of the right-hand frame to press the model stereogram against the negative, and place the frame round the model with the two sides of the angle marked R in contact with the lower right-hand corner of the model. Hold with the right hand the combined negative and frame, and, removing

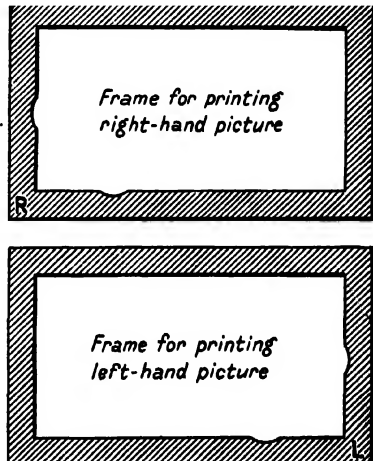


FIG. 50.17. TRANSPOSING MASKS
(Clerc)

the model, turn it over on the table, frame underneath. Fix the negative on the frame with thick rubber solution or strips of gummed paper; do not wet the parts of the strips which touch the gelatine film of the negative. Whilst these strips are drying, proceed with the same registration of the left-hand negative, then verify that there has been no appreciable displacement of the frames by placing the model stereogram in each one in turn, placing it against the lettered angle; if there has been any movement it must be rectified. Whilst the model is in place, mask on each frame the area corresponding to the other negative by means of a piece of black paper (held in place with gummed strips), of which the free edge must coincide with the line of junction of the two prints of the model.

The whole operation, longer to write than to carry out, takes hardly a quarter of an hour from the time the model is ready for use.

The printing can then be done in a single

printing frame or in two printing frames, taking care to place the negatives in corresponding positions, e.g. guiding angles towards the operator. The positive plate will be exposed to light behind each of the two negatives, placing it each time against the register angle. In these circumstances the transparency will be made with the pair of images in the same positions as in the model.

974. Printing of Anaglyphs. Anaglyphs on paper are usually produced by photo-mechanical methods, collotype being convenient for small editions and half-tone for large numbers. Originals sent to the collotype or photo-engraving firm must be very carefully masked, according to the directions set out in § 967. In the case of half-tone reproductions it is well to instruct the engraver to angle the screen as is usually done in three-colour block-making for the red and blue negatives so as to avoid any moiré effect (which would disappear when examined through bi-coloured glasses). If the frames have been suitably placed, the printing must be done so as to ensure their coincidence.

For the production of anaglyph transparencies for direct viewing or projection, the necessary precautions must be taken that the two images, printed on separate plates, occupy the correct positions relative to one another when placed film to film—the edges of the plates coinciding. The blue image may, for example, be made by prussian blue toning (§§ 748 and 751), or by dye-toning with methylene blue made slightly greenish by methylene green or malachite green; the red image may be made by imbibition without washing out (§ 822) by means of ammoniacal carmine, the image printed from a positive being thus reversed.

The red image may also be made by the same methods as the blue, but using a thin film. For making anaglyphs films have been placed on the market with a positive emulsion giving images of weak contrast and without a gelatine coating on the back. These are exposed under a specially prepared transparency (§ 712), and after development they are bleached in the bromoil bleaching bath (§ 845) rinsed, fixed, washed, dried, and dyed (§ 822). The dye fixes on the non-hardened gelatine and a positive image is obtained.

STEREOSCOPIC PROJECTION

975. Classification of the Various Methods. The various known methods of stereoscopic projection may be classified as follows—

(A) The images are projected one on the other and are selected—

(i) By alternately cutting out the two projected beams, with synchronized cut-out of the individual viewing apparatus.

(ii) By their colour, each observer being supplied with an appropriate bi-coloured pair of spectacles.

(iii) By polarization in different directions of the light in each of the projecting beams, each observer being provided with an analysing apparatus.

(iv) By purely geometric means of less general application, stereoscopic vision only being possible to a single observer, or several observers in certain definite positions.

(B) The images are projected side by side, the enlarged stereoscopic pair on the screen being examined—

(i) By a mirror stereoscope.

(ii) By special binoculars.

(iii) By prisms.

(iv) By a mask permitting each eye to see only one image.

976. Alternating Viewing. This method, sometimes called stroboscopes, was described in 1858 by J. Ch. d'Almeida. The two images are thrown by two projectors illuminated alternately with a frequency of about 15 exposures per second for each image. In front of each observer a system of two eye-holes or two eyepieces is provided with shutters synchronized with those of the projectors, so that the right eye sees only the right image and the left eye the left image, with persistence of vision for both eyes.

Nothing appears to show that these projectors were actually made by d'Almeida. The application of this principle to stereoscopic cinematography (with the possibility of using only a single projector, the film consisting of alternate right and left-hand pictures of the same scene) has been patented many times since the beginning of cinematography, notably by Dr. Doyen (1900), by Grivolos (1901), by E. Reynaud (1902), and by G. Schmidt and C. Dupuis (1903); the latter ran a cine-stereoscopic show for several months in Rue d'Hauteville, Paris; each spectator was provided with a species of opera glasses attached to his chair by electric wires, which controlled an electro-magnetic shutter.

977. Projection in Two Complementary Colours. In the same paper in which the above process was suggested, d'Almeida wrote of a method of stereoscopic projection, using projecting beams of red and green for the two images

of the pair. By placing in front of the eyes red and green glasses complementary to each other, the red beam is extinguished by the green filter so that the eye, seeing through the green filter, sees only the image projected with green light, whilst, for the same reason, the other eye, looking through the red filter, sees only the image projected with red light.

Soon after this publication, Rollmann claimed the priority of a similar process for the projection of stereoscopic pictures (§ 951).

Many attempts have been made to reduce the fatigue resulting from the very different sensations experienced by the two eyes by using, both on the projectors and on the analysing glasses, complementary filters of nearly neutral tints. F. E. Ives in 1896 claimed to have succeeded in making two filters practically uncoloured, one transmitting the extreme red and a narrow band in the middle of the green, whilst the other transmitted two other spectral groups, one, on both sides of the yellow, and the other in the blue-violet region. The same results were obtained about 1906 by R. Luther.

A paper was published by H. Lehmann (1917), describing an apparatus for stereoscopic projection of ordinary stereograms in complementary colours (by ordinary stereogram is meant two black images side by side). A projector using an arc and single condenser is fitted with two equal prisms joined by their edges along the line of junction of the two images of the pair, and two lenses of variable separation. He also points out that by suitable adjustment of the regions of transmission of the filters used, so that the transmitted luminosities are equal, it is possible to suppress all effect of colour in the projection of the pictures in black and white, for an observer seeing normally in colours, or to project stereograms in colour without alteration of their tints. He indicates the following liquid filters as fulfilling *approximately* the above conditions: a solution of copper sulphate saturated when cold in a cell 15 mm thick, and a solution of potassium bichromate saturated in the cold and acidified with sulphuric acid in a cell 10 mm thick. Yellow and slightly purplish blue filters, each transmitting a different portion of the green and a different portion of the red, were made in 1933 by L. Lumière. The visual energy received by the two eyes being the same there is no fatigue. These filters have been used in stereoscopic cinematography.

This method of projection, employing two

complementary colours, has been claimed, in its application to cinematography, by Grivolais, in a patent in 1901, and since then by innumerable inventors. The different variations of the process employ either two simultaneous projectors or alternate projection of the left- and right-hand pictures with the use of suitable colour filters on the shutter or alternate tinting of the images themselves on the film.

The stereoscopic "Chinese shadows" (incorrectly called anaglyphs on the programmes of the music-halls exhibiting this attraction), due to L. Hammond (1923), are based on this type of projection. Two ordinary projectors situated behind the stage illuminate a transparent screen, one with red and the other with green light. A person or object situated between the projectors and the screen appears on the screen as two shadows, one in red and the other green. If the left-hand projector, relative to the audience, has a red filter, and if bi-coloured spectacles are worn so that the left eye is covered by the red filter, the observer sees in front of the screen a single shadow of the object in silhouette. This shadow will appear nearer the audience the nearer the object is to the projector, and a scene will have a greater exaggeration of depth the greater the separation of the projectors. By reason of the known laws governing the deformation of reconstructed objects when viewed stereoscopically under abnormal conditions, any object thrown towards the projectors will appear to be thrown towards each individual of the audience whatever his position in the theatre.

978. Projection of Anaglyphs. At the same time as he applied the anaglyphic method to the production of stereoscopic pairs of large size on opaque supports (§ 951), Ducos du Hauron applied the same principle to the production of transparencies for projection.

The application of the anaglyph to cinematography was first pointed out, we believe, by O. Gersacevics and E. Franzos (1907), who described the production of anaglyphic film by superposition, after suitable toning, of two positive films placed gelatine to gelatine, one having been printed from a negative back to front. Many patents taken out since then claim the idea, but make use of films coated on both sides, as currently used in various two-colour cinematograph processes.

Vectographs may be projected successfully provided the screen does not depolarize the light (e.g. as a rule a silver screen is used).

979. Projection in Polarized Light. The use

of polarized light (§ 122) for stereoscopic projections seems to have been suggested first by Otto Wiener. It was first put into practice in 1891 by John Anderton, who showed the process in public in London for some time. The projection was made on a screen which did not depolarize the light (silver paper mounted on calico). Two projectors were used, one beam being polarized horizontally and the other vertically by piles of plates, the construction of which was very minutely described in the patent. The projected images were examined by means of binoculars fitted with similar piles of plates.

Although this process has been described in various periodicals and in a great number of treatises on stereoscopy, it has been re-invented many times. Its application to cinematography was claimed in 1908 by Boris Weinberg. Since the invention of Polaroid this method has become much simpler, as the piles of plates can now be replaced by single polarizing filters both for projecting and viewing. The efficiency of the method is improved as well as the convenience.

980. Geometrical Separation of the Two Images. About 1860 Claudet pointed out a process for stereoscopic projection, which, unfortunately was only visible to one person in a definite position. The two images are projected obliquely on a slightly ground glass, each in the direction of the eye to which it corresponds. Each eye sees the two images, but one of them appears much clearer than the other.

A more exact arrangement, but of equally limited application, was described under the name of the "*concentration stereoscope*" by G. Jager (1905). The images were projected on a lens in such a way that the eyes could occupy the conjugate points of the exit pupils of the projecting lenses.

A process suggested in 1908 by E. Estanave is a more complete solution of the problem, a large number of positions for stereoscopic viewing being possible, but the practical difficulties of the *stereoscopic screen*, i.e. a transparent diffuser having in front of it a vertical line grating (§ 953), have not permitted of its practical use.

981. Stereoscopic Viewing of a Pair of Images Thrown on a Screen Side by Side. The various arrangements already described for viewing large size stereograms are applicable to a pair of images thrown side by side on the screen.

A stereoscope having two mirrors in front of

one eye (§ 948) was described in 1899 by J. H. Knight for viewing stereoscopic projections.

The use of Galilean binoculars with variable separation of the objectives was proposed in 1903 by A. Papigny for viewing stereograms of large size and for stereoscopic projections. The use of this idea for cinematography was claimed by Prépognot (1904).

The use of pairs of prisms of adjustable orientation was described by Moëssard for viewing stereoscopic projections, the two images being either one above the other or side by side. It is simpler, as was worked out by J. Macé de Lépinay, to distribute to each row of the audience (or to the people in several consecutive rows), a pair of prisms adjusted to the angle subtended at each seat by the centres of the two images projected on the screen side by side.

Finally, there is the very simple apparatus used in Brussels in 1891 by M. Moulin. Each spectator held at some distance in front of the eyes a card having a rectangular hole cut in the centre through which each eye could only see its corresponding picture (§ 944).

982. General Precautions. For stereoscopic projection to be viewed without special stereoscopes it is desirable that the distance of corresponding points at infinity in the two pictures should equal the separation of the eyes. This condition cannot be satisfied for anaglyphs except for a single degree of enlargement during projection. In order to fulfil the condition for all degrees of enlargement when projecting two separate lantern slides, both the separation between the two camera lenses and the projector lenses should be equal to the separation of the eyes.

Practical experience has shown that certain conditions must be fulfilled in order to avoid the fatigue to the viewer which results when the eyes are forced to accommodate and converge on different distances. The front planes of the plastic image should be situated at a distance in front of the screen no nearer to the observer than one half of the screen distance. This means that on projection with lenses having parallel axes, the front plane of the plastic image (the front plane for which the pairs of corresponding points coincide, and which is identical with the screen surface) recedes into the plastic image more and more the higher the degree of enlargement. Thus the plastic image extends more and more in front of the screen. The operating conditions should preferably be such that the whole of the plastic

image is situated behind the screen, thus giving the illusion of viewing the scene through a window placed in the plane of the screen (J. T. Rule, 1941).

If a close-up object is projected (especially in cinematography), there is a risk that the plastic image is situated very far in front of the screen. This can be avoided, if the

distance between the taking lenses is reduced or if they are made to converge. With both methods the object may appear to be badly distorted.

It is essential to take into account always the deformations of the plastic image discussed in §§ 939 and 940 and the placing of the edges of the pairs of images (§ 967).

PART 6

COLOUR PHOTOGRAPHY

CHAPTER LI

PRINCIPLES OF COLOUR PHOTOGRAPHY

983. Introduction. We have seen in Chapter I that colour exists only in the observer's brain and—in normal humans at least—the whole appreciation of colour is based on a system of three stimuli. The accuracy of colour appreciation of people with normal vision is extraordinarily high. Indeed few physical instruments can measure colour more closely than the human eye can match sample colours held side-by-side.

Since colour vision is dependent on only three colour stimuli it is theoretically possible to reproduce any visible colour by a mixture of suitable red, green, and blue lights and it is upon this principle that all practical processes of colour photography (with the exception of the Lippmann Process, which will be considered separately) depend.

984. Additive Colour Systems. In 1860 Clark Maxwell gave the first practical demonstration of a process of colour photography. His method was to photograph a coloured object three times, once through each of three filters, red, green, and blue passing bands of wavelengths approximating to the sensitivity bands of the receptors in the eye. From the three negatives (nowadays known as a "separation set") he made three lantern slides which were projected by three magic lanterns so that the three images on the screen fell in superimposition. Over the lenses of the lanterns, the three taking-filters were positioned, the red filter for the lantern projecting the slide from the red-filter negative, and so on. Maxwell showed that the principle was correct but he was hampered by lack of colour-sensitive plates. Colour photography had to wait for the invention of panchromatic plates before the perfectly sound early theoretical work of Maxwell, Cros, du Hauron, and others could be put to proper practical test.

The theory of Maxwell's system is simple. The separation negatives are records of the amounts of red, green, and blue light being reflected from the original subject (or trans-

mitted in the case of such a subject as a stained glass window). Positive transparencies made from the negatives pass red, green, and blue light in proportion to the amounts which were reflected by the original so that the mixture of the three modulated light beams reflected by a white screen is a good reproduction of the original. Whites in the original are represented by clear, or nearly clear, areas on all three positives. Thus a large amount of red, green, and blue light reaches the screen in that area and the addition of the three colours gives a white. This is the reason for the term "Additive System."

Of course, the accuracy of the reproduction depends on the accuracy of the filters, accuracy of exposure and development of the negatives and positives, and proper balance of illumination in the lanterns. In order to get the correct spectral transmission in a blue filter, for example, it is necessary to make it rather dark so that not only would the exposure required for the blue-filter negative probably be long compared with the others but also more light would be required in the blue-filter lantern to bring the final reproduction into balance. There are, of course, limitations to the brightness range of the original subject which can be correctly recorded at the same contrast, just as there are in monochrome photography and for the same reasons. However, providing that these limitations are borne in mind when the photograph is taken, the accuracy attainable by this system is very high indeed.

985. Obviously the three-lantern system is hopelessly clumsy for normal use and attention was turned to the possibility of achieving the same result in a neater way. F. E. Ives invented an instrument which he called a Kromoscope. In this instrument the three monochrome transparencies were illuminated by a single light source and were reflected by a system of semi-transparent mirrors so that the three images could be seen fused together on a ground

glass screen. The colour filters were placed in suitable positions in the optical system. Again, good colour reproduction was attainable but the special piece of optical apparatus was required for viewing.

986. Screen Plates. Another solution to the problem which, in an improved form, has survived as a practical system is the "Screen-plate" process. In the early forms of this process such as the "Autochrome" process, starch grains were dyed red, green, and blue to make tiny colour filters. Equal quantities of the three colours of grain were then thoroughly mixed and sifted on to a glass plate which had been prepared with an adhesive to retain them. This resulted in a glass plate covered all over with a random distribution of tiny three-colour filters, and the interstices between the grains were filled with an opaque medium. On top of the filter layer or "réseau" as it was called, was coated a layer of panchromatic emulsion. The plate was exposed in the camera with the glass side towards the lens so that the light had to pass through the filters to reach the emulsion. The plate was processed by a reversal method to give a positive image. This resulted in a transparency in colour because the individual colour elements were sufficiently small to be confused in the eye at normal viewing distances. Where there was a red object in the original subject there would be an area of red light focused on the plate by the camera lens. The red light would pass through the red filter elements in that area and expose the emulsion behind those elements. The emulsion behind the blue and green elements would be unaffected. After reversal processing, the gelatine of the emulsion layer would be clear behind the red elements and opaque behind the blue and green elements. Thus, that area of the transparency would be seen as red. Where there was a yellow object focused on the plate, the yellow light would pass through both the red and green elements but would be stopped by the blue elements. After reversal processing, the blue elements would be blocked out by a silver density whereas the red and green elements would be clear. At normal viewing distances the tiny red and green elements would be confused in the eye and appear as yellow. Similarly, a combination of varying densities stopping out the three differently coloured elements would reproduce all the various colours in the original subject.

Numerous forms of the "screen-plate" process

have been put on the market but the substitution of ruled screens of coloured elements for the grain réseau is the principal improvement which has been introduced. So far, the finest ruled screen produced is that used in Dufaycolor Film which is still in regular use. Another variation of the system which enjoyed popularity for a long time made use of separate ruled screens for taking and viewing. The taking screens were used in contact with the emulsion of a standard panchromatic plate and could be used over and over again. The exposed plate was developed to a negative and a positive transparency was made from it by contact. The positive was bound in register with a screen, rather similar to the taking screen, to give the final colour transparency. This system had the advantages that only successful pictures had to be bound with a screen so that failures involved only the cost of a panchromatic plate, and that as many duplicate colour transparencies as required could be made from each negative without loss in quality.

987. Although, at first sight, it might appear that accuracy comparable to that of the three-lantern system should be possible with a screen-plate process, there are certain factors which tend to reduce accuracy. Since a screen plate reproduces, say a red, by blocking out the green and blue elements entirely, it is clear that only one third of the total area of the transparency is transmitting light. For this reason additive transparencies are always rather dense. Moreover it is necessary that the red, green, and blue filter elements should appear equally bright in order to give the correct colour balance. This involves some sacrifice of ideal taking-filter characteristics and the accuracy of colour reproduction is thus reduced. Since the individual réseau elements are very small, irradiation in the emulsion causes the image behind one element to spread slightly behind adjoining elements. This reduces the colour saturation of the final transparency. Edge effects in development also cause de-saturation. Nevertheless from the point of view of colour accuracy, the results obtainable with Dufaycolor are equal to any other straightforward process at present commercially available.

988. Lenticular Processes. One other process of additive colour photography should be mentioned. This is the lenticular process typified by the old process of Kodacolor which was marketed for amateur cine photography in the early 1930s (not to be confused with the modern

Kodacolor process which will be described later, § 992).

The lenticular process involves the use of a film coated with a normal panchromatic emulsion on one side and embossed with a pattern of cylindrical lenticles or minute lenses on the other side. A filter consisting of bands of red, green, and blue is placed over the taking lens. The film is exposed through the base side and each of the tiny lenses on the base images the banded filter behind it. In an area corresponding to a red in the original subject a minute image of the red band of the filter will be formed but no light will reach the emulsion from the blue and green bands. The film is processed by the reversal method to give a direct positive so that there will be minute clear areas corresponding to the tiny red images of the filter band and there will be opaque areas corresponding to the images of the blue and green bands. The positive is projected on to a screen with the taking-filter over the projector lens with the coloured bands orientated in the same way as they were on the camera lens. White light will pass through the tiny clear spaces in the positive and will be directed by the little embossed lenses so that it passes through the red band of the filter over the lens and gives rise to a red area on the screen. Similarly, in an area corresponding to a yellow area in the original subject, tiny images of the red and green bands will be focused on the emulsion so that when the film is reversal-processed, there will be clear areas corresponding to the images of the red and green bands and an opaque area corresponding to the image of the blue band. Then, when the film is projected, white light will pass through the clear areas and be directed through the red and green bands to be thrown on the screen as a yellow area. This process is capable of giving good results but one outstanding difficulty is distortion of the film base during processing and drying. Obviously if the spacing or curvature of the embossed lenses changes between exposing and projecting, the light will no longer pass exactly through the correct filter bands when the film is projected and the colour accuracy will suffer.

All the additive processes depend on adding together varying amounts of red, green, and blue light to reproduce the wide range of visible colours. The additive systems will yield only transparencies and a different system has to be used for colour prints on paper.

989. Subtractive Systems. In subtractive

systems of colour photography the basic object is still to control the amounts of red, green, and blue light reaching the eye, but this is achieved in a different way. Positive images are made from colour separation negatives, made exactly as for the additive system, but are in some way made in colours complementary to the negative taking filters. That is to say, a positive in blue-green (normally known as "cyan") is made from the red-filter negative, one in blue-red ("magenta") from the green-filter negative, and one in yellow from the blue-filter negative. These three positives, which may be transparencies or prints, are then superimposed to give the final result in full colour.

It is perhaps unfortunate that such a sharp distinction between additive and subtractive processes has been drawn in the past, because this division has tended to obscure the fact that both systems achieve the object of controlling amounts of red, green, and blue light, only in rather different ways. The cyan positive from the red-filter negative should, ideally, be of such a colour that, in the strongest parts, all the red light incident upon it should be absorbed and all the blue and green light incident upon it should be reflected (or transmitted). With an image of such ideal cyan colour the darkest parts would reflect no red light, but in a middle-tone—which is in effect the cyan colour plus white—a proportion of the red light together with all the green and blue light would be reflected and in a very light tone, most of the red light together with all of the green and blue light would be reflected. In other words, the variable-concentration cyan image should control the reflection (or transmission) of the red component of the incident light. Similarly, the magenta positive from the green-filter negative should be of such a colour that in its darkest parts it would reflect all of the incident red and blue light and absorb all the incident green light; its varying concentrations would control the reflection (or transmission) of green light. The same applies to the yellow positive from the blue-filter negative which should be of such a colour that in its darkest parts it would absorb all the blue light and reflect all the red and green light incident upon it.

A clear understanding of this explanation is necessary and it is therefore considered worth while dwelling a little longer on the relationship between additive and subtractive systems and to use an ingenious illustration first given by E. R. Davies. Imagine three

lanterns set up to project in register monochrome positive transparencies made from a set of separation negatives and with the appropriate red, green, and blue filters over the lenses (i.e. the classical Maxwell additive set-up). The picture on the screen should be a good colour-reproduction of the scene originally photographed. Now imagine it were possible to take the transparency from the "red" lantern and slide it down the beam until it laid in the plane of the screen. Clearly, the monochrome transparency would spoil the image on the screen but it would still be possible for it to fulfil its function of modulating the red light from the red lantern without interfering with the picture if its image were altered from black to cyan. The picture on the screen would now be as it was when the transparency was in the lantern. Similarly, the transparency from the "green" lantern could be placed on the screen if it were changed to magenta colour and lastly, the transparency from the "blue" lantern could be placed on the screen if its colour were changed to yellow. All three positives would now be on the screen and illuminated by unmodulated red, green, and blue light from the three lanterns. However, the three lanterns could now be switched off and a white light switched on, still without changing the picture. This shows clearly that the fundamentals of the additive and subtractive systems are the same.

990. From what has been said it will be obvious that subtractive processes depend on making photographic images cyan, magenta, and yellow in colour. There are many ways of doing this but all depend on making colour separation negatives in one form or another. One of the earliest printing methods was the "carbon" process. A full description of the Carbon process for monochrome photography is given in Chapter XLV, on pigment processes, and it is shown there that it is possible to make prints in a wide variety of colours. Pigment papers are commercially available for making "Tri-chrome Carbon" prints and the method of using them is exactly as described in Chapter LIII. Separation negatives are made from the original subject and the red-, green-, and blue-filter negatives are printed by contact on sheets of sensitized pigment paper cyan, magenta, and yellow in colour respectively. After exposure the pigment papers are wetted and mounted on three separate pieces of waxed celluloid for hot water development. After drying one

of the three images is squeezed on to a sheet of wet, gelatine-coated paper, and dried. When the paper is dry the gelatine image strips from the waxed celluloid and remains on the paper which is re-wetted and brought into contact with the second celluloid. The two images are brought into register by viewing through the celluloid and the paper is squeezed down firmly. The double print is dried and stripped and the third colour is registered, dried, and stripped to give the finished print.

991. A similar set of pigment papers can be used to make colour prints by the "Carbro" method (§ 843). In this case, three bromide prints are made from the separation negatives and from these "Carbro" prints are made in the appropriate coloured pigment papers and developed on waxed celluloids. The assembly of the finished print is the same as from the Carbon process. Various other methods have been proposed for using the principle of sensitization of colloids by bichromates in the production of colour prints. For instance, three sheets of celluloid may be coated with a layer of bichromated glue, dried and exposed through the base by contact one behind each of a set of separation negatives. The glue which remains still soluble and the remaining unchanged bichromate can then be washed away in cold water, leaving reliefs of hardened glue whose thicknesses are inversely proportional to the densities of the separation negatives. The relief from the red-filter negative may then be dyed in a solution of a cyan acid dye, the green-filter relief in a magenta dye solution, and the blue-filter relief in a yellow dye solution. The three reliefs may then be dried and cemented together on a sheet of white paper to form the finished print, or the dye can be transferred, in register, on to a single sheet of paper which has been coated with gelatine containing a mordant (e.g. aluminium sulphate). A slightly different method is to incorporate appropriately coloured pigments in the bichromated glue before coating; it is then necessary to cement the three celluloids together to obtain a print.

There are many methods of obtaining the coloured images which are based on the use of silver halide emulsions for making the basic positives. For instance, suitably coloured pigments may be incorporated in unhardened ordinary "positive" type emulsions and coated on stripping-film base. A sheet of cyan pigmented film is exposed, through the base,

behind the red-filter negative, magenta pigmented film behind the green-filter negative and yellow pigmented film behind the blue-filter negative. After exposure, the three films are developed in a tanning developer (a developer whose reaction products tan the gelatine imagewise in proportion to the amounts of silver developed) and then washed out in hot water to remove the remaining soluble gelatine. The silver is then bleached and the three individual coloured images are stripped and registered together on a single sheet of white paper.

Reliefs suitable for dyeing can be made on films coated with unhardened "positive"-type emulsions. Such emulsion layers usually incorporate a water-soluble screening dye to restrict penetration of the exposing light. As most films of this type are blue-sensitive only, yellow dye is usually suitable for this purpose. In any case the screening dye should wash out during processing. Three sheets of film are exposed through the base behind the three separation negatives, developed in a tanning developer and washed out in hot water to give reliefs for subsequent dyeing. An alternative procedure is to develop the films in an ordinary non-tanning developer, bleach the silver in a tanning chromium bleach and wash out in hot water. This, again, yields a set of reliefs ready for dyeing.

Three pieces of stripping film may be exposed behind the three separation negatives, developed and the silver images converted to the appropriate cyan, magenta, and yellow colours by metal toning. The three images are then stripped and registered together on a piece of paper to give the final print. Alternatively, the three films may be developed in "colour-coupling" developers to give the appropriate colours. "Colour-coupling" developers are so compounded that the oxidation products of the developing agent combine with a substance known as a coupler to give a coloured dye which stains the gelatine of the emulsion in proportion to the amount of silver developed at each point.

Yet another way of converting silver images to dye images is the dye-mordanting process. In this case the silver images are bleached in a bleaching solution which forms a silver compound capable of fixing or "mordanting" basic dyes. Silver iodide, for instance, possesses this property. It is possible to find basic dyes to give colours approximating to the required cyan, magenta, and yellow.

992. The processes described so far have all been known, in principle at least, for a long time and they depend on separation negatives made on separate plates or films. A more recent development is the so-called "integral tri-pack" system of making subtractive transparencies in which the set of three separation negatives is made on a single film coated with three different emulsion layers. The films are coated, first with a highly red-sensitive panchromatic emulsion which is, however, insensitive to green light. On top of this layer is coated a layer of orthochromatic emulsion; over this is coated a layer of gelatine dyed yellow and, finally, on top of that a layer of blue-sensitive emulsion. This "tri-pack" material is exposed in the camera with the emulsion side towards the lens and, when it is developed there is, in effect, a set of three separation negatives in a pile. Only the red light reaching the film can affect the bottom layer because it is insensitive to green, and blue light will not reach it because the yellow filter layer will not pass blue light. Thus the bottom layer, after development, will be a red-filter negative. The green light reaching the film will affect only the middle emulsion layer because it is the only green-sensitive layer; on the other hand the middle layer will not be affected by red light because it is insensitive to red, and blue light will not reach it because of the yellow filter layer. Thus, the middle layer, after development, will be a green-filter negative. The blue light reaching the film will affect only the top layer because it is the only layer above the yellow filter; on the other hand it will not be affected by red or green light because it is blue-sensitive only. Thus the top layer, after development, will be a blue-filter negative.

For these negatives to be any use it is necessary to convert them into colour positives *in situ*. This can be done in two main ways. The first method is to develop the film in an ordinary developer to produce the three separation negatives and then to expose the film uniformly to red light from the back. This will expose the parts of the bottom emulsion which were unaffected by the first exposure and development but will not affect the other layers which are insensitive to red light. The next stage is to develop the film in a cyan colour-coupling developer; all the silver in the bottom layer is now developed but, in addition, the gelatine of the bottom layer contains a positive cyan dye image formed during the second development.

The film is now exposed to the blue light from the front. This exposes the parts of the top emulsion which were unchanged by the first exposure and development. The next stage is to develop the film again in a yellow colour-coupling developer; all the silver in the top layer is now developed, but in addition the gelatine of the top layer contains a positive yellow dye image. The film is next developed in a fogging magenta colour-coupling developer which affects only the parts of the middle layer which were unaffected by the first exposure and development, since this is the only part of the three emulsions which has not already been developed. Thus all the silver in the middle layer is now developed, but in addition the gelatine of the middle layer now contains a positive image in magenta dye. Finally, the silver is bleached in a solution which also decolorizes the yellow filter layer but does not affect the dye images. The finished result is a transparency in full colour. Kodachrome is a film of this type, and so is Ilford Colour film, although the latter material varies slightly from this general description in both its manufacture and processing. Integral tripacks of this type are invariably processed by the manufacturers.

The second method of carrying out the "integral tri-pack" process is more complicated for the emulsion-maker but much simpler to process. The film is coated, as before, with the three differently sensitized emulsion layers, but this time the colour couplers are incorporated in the emulsion layers; the cyan coupler in the red-sensitive layer, the magenta in the green-sensitive layer, and the yellow in the blue-sensitive layer. The film is exposed as before and developed to a negative in an ordinary developer. It is then exposed to white light and re-developed in a developer compounded to react with the couplers in the emulsions. In this second development all the remaining silver is developed and, simultaneously, the dye images are formed in the appropriate layers. Finally the silver and the yellow dye layer are bleached out to leave the transparency in full colour. Agfacolor, Ansco color, Ektachrome, Ferranicolor, and Gevacolor are materials of this type. The method adopted to prevent the couplers diffusing from their appropriate layer is different in the case of Ektachrome to the other four, all of which are based on the Agfacolor process.

It is possible to apply the same principle

to the production of prints. One method (Ansco Printon) is to coat a white acetate film in a similar way to that already described and to expose it by projection to an "integral tri-pack" transparency. The film is processed in a similar manner to that described but, since the film base is white, the finished film can be viewed by reflection as a print. It has not so far been found possible to carry out the reversal processing necessitated by this method on a paper base.

An alternative method is to develop to a colour negative, the "integral tri-pack" film which is exposed in the camera. That is, to cut out the stage of first development in the ordinary developer and to develop the film straight away in the colour developer, bleaching the silver and fixing out the remaining unexposed silver halide. This results in a negative in dyes which is not only negative as regards black and white but also represents all the colours of the original subject by their complementary colours. Such a negative can be printed directly on paper coated with the tri-pack emulsions. This material, again, is developed directly in the colour developer to give, after bleaching the silver, a print in full colour. Since there is no reversal processing of the print it is possible to make the material on a paper base. The modern Kodacolor process works in this way as does Ektacolor. Ektacolor, however, is intended for print making by a modification of the Dye Transfer Process.

The outstanding advantage of the "integral tri-pack" system is the fact that the colour separation is made in one exposure in an ordinary camera, and films made for this purpose, although slow by the standards of monochrome photography, are fast enough for action photography. If it is desired to make prints by one of the methods described, it is always possible to make ordinary separation negatives from a colour transparency. The methods of doing this will be described in detail in Chapter LII on Separation Negatives.

As has been mentioned, only the subtractive processes can be used for making colour prints on paper. They are also useful for making colour transparencies and these have the advantage that they pass at least three times as much light as additive transparencies and that they have no réseau to impair their definition.

993. The outstanding disadvantage of the subtractive processes is the unfortunate fact that there are no dyes or pigments known which

fulfil the theoretical requirements of the cyan and magenta printing colours. In general, available yellows are fairly satisfactory but the best cyan colours absorb green light to a serious degree and the best magenta colours absorb seriously in the blue. Thus the accuracy attainable by subtractive systems with available materials is inferior to that obtainable by additive systems. This will be referred to again in the chapter on Separation Negatives.

The integral tripack known as Ektacolor, referred to earlier, attains a rather higher accuracy of reproduction by the provision of integral masking (§ 1005). This is achieved by the use of couplers which are themselves coloured, their inherent colour being destroyed as the normal coupling action takes place.

The inherent colours of the couplers are chosen so that the coupler which remains unused after processing serves to cancel the unwanted green and blue light absorptions of the cyan and magenta dyes. This gives the complementary colour negative an odd appearance but results in prints of improved accuracy.

994. The Lippmann Process. This obsolete process is the only one which does not fall naturally into the category of either an additive or a subtractive process. It was carried out by exposing a panchromatic plate, the emulsion of which was almost transparent, with its emulsion surface in contact with a metallic mirror. This

was achieved by building special dark slides which allowed mercury to be run in behind the plates in order to ensure optical contact between the emulsion and metallic reflecting surface. Light passed through the emulsion and was reflected back by the mercury surface, but the light on the return passage through the emulsion layer was out of phase with that on the first passage. Thus an interference was set up and this resulted in the emulsion layer being rendered developable where the peaks of the waves coincided. The distribution of the image through the thickness of the emulsion layer when the plate was developed, was therefore dependent on the wavelength of the exposing light at every point on the picture. The developed negative was backed up with a mirror and viewed by reflected light. When the plate was illuminated and viewed at the correct angle the picture was seen in full colour. At every point in the picture light of all wavelengths, other than those which gave rise to the image, was absorbed. Those wavelengths which could go through the image and, after reflection, come back through the image, gave the correct colour sensation. From a scientific point of view this is an extremely elegant process but in practice it is not very useful. Not only are the taking and viewing conditions critical and difficult to satisfy but emulsions of sufficient transparency are very slow.

CHAPTER LII

SEPARATION NEGATIVES

995. General. All methods of making colour prints depend on separation negatives. There are a number of different ways of making separation negatives but certain basic principles apply to them all. It is most important that all the negatives in a separation set should have the same contrast and should make use of the same part of the characteristic curve of the negative material. To facilitate the achievement of these requirements a reference scale of greys should always be included in the subject in a position near one edge so that it can be trimmed off the final print without spoiling the picture. This grey scale or "wedge" should range from white to black and should, ideally, be recorded identically in the three negatives. To achieve this it is necessary to determine accurately the filter factors for the three filters and, since the contrast of most emulsions varies with the colour of the exposing light, to adjust the development times for the three negatives.

Very great care in exposure and development is absolutely essential. The foundation of a good colour print is a good set of negatives. It is desirable to determine the filter factors and development ratios for each batch of plates as there is often a marked difference between different batches of the same product. For this reason it is most economical in time and material to buy the sensitive material for negative-making in batches large enough to last for, say, six months' work.

996. Developing. It is essential to standardize development conditions to a degree which is unnecessary in ordinary monochrome work. It is normally advisable to develop the three negatives of a separation set simultaneously in order to minimize variations in contrast due to variations in temperature and agitation conditions. Negatives up to 5 in. \times 4 in. are most conveniently developed in tanks. A small tank with a rack to take one dozen plates is convenient and may be used to develop four sets of negatives simultaneously. A metol-hydroquinone tank developer is probably the most satisfactory and its dilution should be adjusted so that the development times are between 5 and 10 minutes. The developer should

be brought to the correct temperature (68°F is convenient) and poured into the tank. The temperature should be checked in the tank just before development is commenced. The nearer the room temperature can be adjusted to the development temperature, the simpler the problem of maintaining solution temperatures becomes. Where large volumes of separation negative work are to be handled, it is highly desirable to arrange for close control of room temperature. Alternatively, the developing tank or tanks may be stood in a large tank of water at the correct temperature. After checking the temperature the lights are turned off and the plates are loaded in the developing rack in total darkness. The plates must be loaded systematically so that the negatives taken through the different filters may be withdrawn from the developer at different times. The rack is slid steadily into the developer and agitated vigorously for a few seconds in order to dislodge any air-bubbles. The rack should be left still for one minute and then lifted clear of the solution and replaced. This should be repeated every minute throughout the development time but no other agitation should be given. When the shortest development time has elapsed (this will be for the red or green filter negatives according to the particular material in use) the appropriate negatives should be lifted out of the rack and quickly slid into a stop-bath of 2 per cent acetic acid. The plates should not be rinsed in plain water because development would continue and tend to give erratic results. The rest of the negatives should be withdrawn from the developer at the appropriate times and placed in the stop bath. All the plates should then be transferred to the fixing bath for fixing in the usual way. After thorough washing the plates should be placed in a drying rack so that all the images in a set are the same way up. This is very important because slight variations in density are likely to appear between those parts of the negatives which dry first and those which dry last. This is unimportant if the variation is the same on all the negatives in a set, but if there are differences between them, the unevenness is liable to show in the finished print. The

developer and stop bath should be discarded after use.

Negatives larger than 5 in. \times 4 in. are usually developed in dishes. It is desirable to have a dish for each negative and, in order to ensure equal agitation throughout the set, the three dishes should be arranged side by side on a single board fitted with rockers similar to a rocking chair. Sufficient developer for the three dishes (500 ml for each 10 in. \times 8 in. dish) should be brought to correct temperature in a jug and then poured into the dishes. The temperatures should be checked in the dishes. Temperature control is very much more difficult in dishes than in a tank so that it is almost essential to bring the room temperature to somewhere near the development temperature; otherwise it may be found that the developer has gone up or down several degrees during development. This would make it very difficult to get exactly the desired contrast in the negatives. It is difficult to put three plates into the dishes simultaneously so the most convenient method is to put them in at intervals of about 30 seconds starting with the blue-filter negative which will require the longest time. Care must be taken that the intervals chosen do not result in the necessity of removing the three plates simultaneously as this is impossible for a single operator to achieve. The dishes on the rocker should be rocked continuously but irregularly and an occasional lengthwise tip should be given to the rocker in order to set up cross currents in the dishes thus avoiding regular waves which would result in patchy development. As each plate is removed from the developer, it should be placed in a stop bath and then transferred to the fixing bath.

997. Control Methods. While it is undoubtedly possible for very experienced operators to judge the balance of separation negatives, provided a grey scale is included, this is very difficult and never very certain. It is highly desirable to make use of a densitometer in establishing the optimum conditions of exposure and development for a particular batch of material and for checking sets of negatives as they are made.

The best way of establishing filter factors and development ratios for a batch of negative material is first to plot a gamma-time curve (§ 380) under the conditions to be used in practice. If both tank and dish development are to be employed, the gamma-time curve must be plotted for both conditions. Next, a neutral

step wedge should be photographed three times, once through each of the tri-colour filters using the filter factors quoted by the manufacturer of the sensitive material. The three negatives should be developed for the time necessary to give a gamma approximately suitable for the printing process to be used and giving 25 per cent extra development time to the blue-filter negative. When the negatives are dry, the densities of the wedge steps should be measured on all the negatives and these densities should be plotted against the densities of the original wedge. The ideal is to make the curve for each of the three negatives fall exactly on top of the others. It is very unlikely that this will be the case in the first experiment but, by reference to the negative curves and the gamma-time curve, it is fairly simple to estimate the adjustments in exposure and development necessary to get close to the ideal. A second set of negatives should now be made with the corrected exposures and development times and their reproduction curves plotted. This time the curves should be very close together but it may still be necessary to make some minor adjustments. If more than one type of light-source is to be used for making negatives, e.g. daylight and tungsten filament lamps, it is necessary to determine the filter factors for each set of conditions. Provided that this initial testing work is carefully carried out and that exposure and development conditions are always carefully controlled, it should be possible to obtain properly balanced negatives every time. However, it is desirable to check the balance of every set as it is made, by taking density measurements on the two end steps of the wedges on each negative.

998. Balance and Register. In all separation negative work it is very important to avoid mixing lights of different qualities for making the exposures. For instance, in studio work no daylight must enter and it is not permissible to mix arc spots and tungsten general lighting.

Obviously it is important that all the negatives in a set shall be exactly the same size so that prints made from them shall register when assembled together. Many lenses which are satisfactory for monochrome photography are unsuitable for colour separation work because they give images of different sizes through the three filters. A high-grade apochromatic lens should therefore be chosen for colour work and should be tested for register before use. Filters for separation work should be

cemented between optical flats and supplied as matched sets, or in the form of thin gelatine films, otherwise they will upset the negative register even with a good lens. Gelatine filters are very much cheaper than optical flats, but are easily damaged; they must be renewed as soon as they become marked or buckled.

999. Methods of Exposure. (i) *Using an Ordinary Camera.* The method of exposing separation negatives which requires the least specialized equipment is to take three negatives, one after the other, in an ordinary camera. Obviously, only inanimate objects can be photographed in this way and the camera must be very rigidly mounted on a tripod. Landscapes can be photographed on still days but if there are sharp shadows it is important to complete the three exposures within five minutes otherwise colour fringing due to movement of the shadows with the Earth's rotation will become obvious in the finished print. Field cameras are most convenient for this work but any rigid plate camera will do, provided it is fitted with a suitable lens. The darkslides should be checked for register and, if necessary, adjusted until they all hold their plate in exactly the same plane. Cut sheet films can be used in place of plates if desired, in which case they should be loaded in film sheaths. Great care should be taken that there are no bulges in the film. It is possible to use a roll-film camera, winding the film on between each exposure, but generally speaking this is not very desirable because it is not convenient to develop the three negatives for different times. If the negatives on a roll-film are developed all for the same time they will differ in contrast so that it is necessary to compensate for this in the printing process. Generally speaking, this is not desirable.

Tri-colour filters are supplied by all the leading manufacturers of photographic materials. Most panchromatic materials as used for ordinary monochrome photography can be used for separation negatives but there are some exceptions. For this reason the makers' literature should be consulted before choosing a material.

If gelatine filters are used, it will be found convenient to mount them side by side in a cardboard frame which can be slid through a slotted lens cap. This facilitates handling and changing of filters without touching their delicate surfaces.

Usually, it is necessary to arrange the lens

aperture so that the shortest of the three exposures is not less than five seconds, otherwise it is very difficult to time the exposures with sufficient accuracy. There is not usually available a sufficiently wide range of shutter speeds to allow snapshot exposures to be made with accuracy. It is not advisable to change the lens aperture to compensate for the different filter factors as the depth of field in the three negatives would then be different. It is possible to combine neutral density filters with the colour filters so as to bring all their factors to the same value. However, there is no disadvantage in giving short time exposures because the subject must be still to make this method of separation negative-making feasible at all.

1000. (ii) Repeating Back. It is obvious that for many subjects it would be an advantage to expose the three negatives in very quick succession. "Repeating backs" are made for this purpose and consist of a slide fitted with three colour filters side by side, each the full size of the negative. This slide is fitted on the back of an ordinary field camera and may be slid into three positions so that each of the filters may be centred with the lens. A single darkslide holding three plates side by side fits behind the filter slide so that three exposures may be made simply by moving the back along between exposures. This saves all the time of changing darkslides between exposures and the whole operation of exposing a set of negatives in a manually-operated repeating-back may be carried out sufficiently quickly for photographing, say, cut flowers.

Various degrees of mechanization have been applied to repeating backs and the "Vivex" fully automatic back which was made until 1939 not only moved the back but also operated the shutter to give three correct exposures. With this apparatus it was possible to expose the whole set in $1\frac{1}{2}$ seconds so that living models could be photographed.

Shorter exposures are possible with automatic or semi-automatic repeating backs if the "blue-filter" separation negative is made on a fast blue-sensitive plate with no filter and the "green-filter" negative is made on a fast orthochromatic plate with a yellow filter. The red-filter negative must, of course, still be made on a panchromatic plate with a red filter. By this method it is more difficult to obtain three negatives with identical reproduction curves than is the case when all three negatives are made on the same material. Ideally, the

same "parent" emulsion unsensitized, orthochromatized and panchromatized should be used. In any case it is advisable to consult the manufacturer before choosing the materials for the purpose.

1001. (iii) Tri-pack. Naturally, it has always been the aim of the colour photographer to be able to take colour photographs of action subjects and it is the facility with which this may be done with one of the transparency processes which has been largely responsible for their popularity. Inventors have turned their attention to methods of making sets of separation negatives with one exposure from the earliest days of colour photography and one solution to the problem, now almost obsolete, is the "tri-pack."

Three sensitive materials are arranged as a pack. The bottom material has an emulsion which is highly red-sensitive but insensitive to green, and is usually in the form of an antihalation backed plate to give rigidity to the pack. The next layer is an orthochromatic film coated on a very thin base with an even backing of yellow-dyed gelatine. This film is placed emulsion to emulsion with the panchromatic plate. The top layer is a fast blue-sensitive material which may be either an unbacked plate or film. This is placed emulsion side to the yellow side of the middle film. The pack of three materials is exposed from the blue-sensitive side in an ordinary camera and a record is made on the three materials simultaneously. The first layer is blue-sensitive only and therefore records the blue light only. The yellow filter layer now absorbs the blue light and transmits the green and red light. The middle layer is green-sensitive and red insensitive while the back layer is red-sensitive and green insensitive so that they record the green and red light respectively.

The difficulties associated with this system are serious. Firstly it is necessary to make the three materials of such speeds that correctly exposed negatives are obtained with a single exposure. Suitable allowance has to be made, of course, for the optical densities of the top two emulsion layers which affect the exposures of the underlying layers. Secondly, the top layer must be made as transparent as possible so as to reduce light-scatter to a minimum and obtain adequate definition in the lower layers. In general, the requirements of high sensitivity and transparency are conflicting. Thirdly, the film or films in the pack must show the

minimum base distortion during processing and drying otherwise the final images on the films will be different in size from those on the plates.

In fact, materials with practically useful speed transmit light which is scattered so much that the back negative is always seriously unsharp. Unfortunately, the red-filter negative seems to be the most important from the point of view of definition and any unsharpness is quite obvious on the finished print.

1002. (iv) One-shot Cameras. An altogether more satisfactory way of obtaining a set of separation negatives with a single exposure, involves the use of a specially constructed camera which optically splits the light passing through the lens into three parts and produces images at three different stations. This is achieved by incorporating two partially transparent mirrors inside the camera. There are several possible arrangements but the one shown diagrammatically in Fig. 52.1 is satisfactory. The reflectors may be made of glass with a metallic coating of suitable density. This coating may be silver in which case it may be deposited chemically or it may be one of the precious metals deposited by sputtering or by evaporation in vacuum. Glass reflectors are fairly robust in use but there are several difficulties associated with them. Since glass has appreciable thickness trouble is experienced with double images caused by reflection from both sides. This can be overcome by coating filter layers on the backs of the reflectors, choosing the filter colour so that it reflects a colour which will have no effect on the plate receiving the reflected image, but transmits all the light of the colours required at the other stations. For instance the reflector nearer to the lens may be yellow backed and the second reflector magenta backed. It is extremely difficult to design a glass reflector optical system such that the three images will register accurately. For this reason, successful cameras with glass reflectors have been designed for use in conjunction with compensating printing devices. Unless the reflectors are at 90° to each other and 45° to the lens axis, "wedging" (i.e. variation in the illumination due to reflection for varying angles of incidence) at one or more of the focal planes results.

Most of the difficulties of design can be overcome at the expense of some loss of robustness, by the use of extremely thin "pellicle" reflectors. These are usually collodion skins a few microns thick stretched on optically flat

metal frames. They are sometimes metallized by sputtering.

The three filters are positioned just in front of the focal plane at each of the three stations. Three panchromatic plates may be used with the ordinary tri-colour filters or the "blue-filter" negative may be made on a blue-sensitive plate without filter and the "green-filter" negative made on an orthochromatic plate with a yellow filter.

Naturally, the one-shot cameras are very expensive but they undoubtedly represent the best solution to date of the problem of making direct separation negatives from moving subjects. On the other hand, they are less flexible than ordinary field cameras in that they are usually designed for use with lenses of only one focal length and cannot be fitted with such useful movements as "swingback."

1003. (v) "*Bi-pack and One.*" A compromise system which uses a special camera of considerably simpler design and cheaper construction than the two-mirror one-shot camera has been called the "Bi-pack and one" system. The camera has a single reflector and the reflected beam is used to make the red filter negative. The transmitted component of the light is used to make the "blue-filter" and "green-filter" negatives on a bi-pack. The material nearer the lens is a yellow-backed, blue-sensitive film behind which is an orthochromatic plate or film. This method suffers from the defects of the tri-pack system although to a lesser degree and although the camera is cheaper to construct it has the same limitations as a two-mirror one-shot camera. Cameras of this type have been made by amateurs from old reflex cameras, the reflex mirror being replaced by a pellicle and a dark-slide fitting being put in place of the top focusing screen. Unfortunately the necessary bi-pack materials for cameras of this type are no longer available.

1004. (vi) *Separation Negatives from Colour Transparencies.* Another method of obtaining separation negatives is to make a colour transparency by one of the "screen-plate" or "integral tri-pack" processes from the original subject and subsequently to make separation negatives from the transparency. This method has a number of advantages. Firstly, an ordinary camera can be used, and it is possible to select a lens of suitable focal length and make use of any camera movements even when photographing moving subjects. Secondly, the picture can be seen in full colour before the separa-

tion negatives are made so that it is not necessary to go to the expense of making a colour print if the transparency is in any way unsatisfactory. Thirdly, the separation negatives can be made at leisure and can be re-made at any time in the event of anything going wrong in the processing of the negatives or accidental damage to them. Against the advantages must be set the disadvantage that all the errors which are

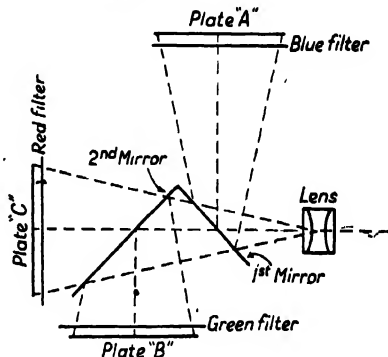


FIG. 52.1 SCHEMATIC LAYOUT OF A TYPICAL ONE-SHOT CAMERA

inherent in systems of colour photography are involved twice, once in making the transparency and again in reproducing it. In the case of "screen-plate" transparencies there is a definite limit to the degree of enlargement of the final print which is set by the réseau. Obviously, the coarser the réseau elements, the less the possible enlargement before either the pattern shows in the print or the print becomes noticeably unsharp. In general, it is better to make separation negatives from integral tri-pack transparencies than from screen-plate ones. As the separation of the colours has already been made when the transparency was made, the problem in making separation negatives from a transparency is different from that of making them directly from the subject. All that is required is to analyse as completely as possible the three images of which the transparency is composed. No overlap of the transmission bands of the tri-colour filters is required so "narrow-cut" or "analysis" tri-colour filters should be used for this purpose. These give negatives with considerably better colour separation.

The negatives can be made in three different ways. The transparency can be set up with

diffused light behind it and photographed in a camera. It can be put in a light-tight enlarger fitted with an apochromatic lens and negatives can then be made by enlargement (this is the best way of dealing with the popular 35-mm transparencies). Mercury-vapour enlargers are not suitable for this purpose because the mercury tubes give no red radiation. The negatives can be made by contact from the transparency using a light source in a light-tight housing having an aperture over which the analysis filters can be positioned.

Ideally, a neutral grey step-wedge should be included when the original transparency is made so that the image of the wedge may serve as a guide to the making of the separation negatives. This method results in partial compensation for slight inaccuracies in colour balance of the transparency itself. Unfortunately, the photographer is often faced with the problem of making negatives from existing transparencies which do not include the step-wedge. In the absence of a wedge on the transparency itself a silver wedge made on film and having a density range similar to that of the transparency should be mounted alongside. As in all separation negative work, the wedge should be recorded identically on the three negatives.

When the separation negatives are to be made from "screen-plate" transparencies precautions have to be taken to eliminate the réseau pattern on the negatives. If the negatives are being made in the camera or in an enlarger, this may be accomplished by putting the image very slightly out of focus. Care must be taken, however, not to make the image more unsharp than is absolutely necessary because the resolution of the transparency itself is already limited by the réseau. An alternative method of eliminating screen pattern is to use a very small lens aperture. This lowers the resolving power of the lens owing to diffraction effects caused by the very small aperture. This method will, of course, result in rather long exposure times unless the light intensity is very high but this is not usually of primary importance. When the negatives are being made by contact the same effect can be obtained by slightly spacing the emulsion surface of the transparency from that of the sensitive plate. In the case of film transparencies such as Dufaycolor, this is achieved very simply by putting the sensitive plate in contact with the base side of the transparency.

In the case of plate transparencies the same effect can be obtained by employing a spacer of clear film base.

1005. Masking. The principal difficulty encountered in reproducing integral tri-pack transparencies is due to their very long density range. It is not at all uncommon for a Kodachrome transparency, for example, to have a density range of from 0.2 in the high-lights to 3.0 in the shadows and detail, which it is important to retain, at both ends of the scale. This represents a brightness range of about 630 : 1 which is too long to be correctly recorded on a print by straightforward means. It is very desirable to reduce the brightness range of the transparency by combining it with a monochrome negative made by contact from the transparency itself. This has the effect of adding neutral density to the highlights without affecting the shadows, thus allowing sufficient exposure to be given adequately to record the shadow detail. It also results in increased colour saturation in the final print which to some extent offsets the loss of contrast which is inevitable in a print made from a transparency. This contrast-reducing "mask" should preferably be made slightly unsharp to facilitate subsequent registration and should be made on a panchromatic material. It is possible to introduce a measure of control over the relative brightness of colours in the reproduction by exposing the contrast mask by coloured light. In practice, the tendency is for blues and greens in the reproduction to be darker than they were in the original subject and this defect may be minimized by using light filtered by a tri-colour red filter for exposing the mask. The exposure should be just sufficient to record the detail in the shadows of the transparency and the mask should be developed to a gamma of between 0.3 and 0.4. The mask plate should be exposed in contact with the base side of the transparency in order to introduce a certain amount of diffusion. After processing and drying, the transparency should be registered carefully with the mask and taped down on it with thin transparent adhesive tape. The transparency will now be emulsion side upwards so that separation negatives can be made by contact emulsion to emulsion. If the negatives are to be made in the camera or enlarger it is advisable to bind a cover glass over the transparency to prevent it curling away from the

Apart from the special considerations noted

above, the rest of the procedure for making separation negatives from transparencies is the same as has been described for negatives made directly from the original subject.

1006. Colour Correction by Masking. In Chapter LI it was noted that colour photographs made by subtractive processes cannot be accurate because available colours for making the cyan and magenta components of the image do not fulfil theoretical requirements in that they have serious unwanted absorptions. The principal defects are unwanted absorption of green light by the cyan colours and unwanted absorption of blue light by the magenta colours. In other words, the "cyan" colours are almost blue and behave as mixtures of theoretical cyan and theoretical magenta while the "magenta" colours are almost red and behave as mixtures of theoretical magenta and theoretical yellow. The type of errors in reproduction which result from these defects are purples and greens, rendered too dark and degraded; magentas rendered too red and peacock blues rendered as prussian blue.

It is possible largely to compensate for these errors by a secondary photographic process known as colour "masking" at the separation negative stage. Since the cyan image will, in fact, be printed in what is really a mixture of cyan and magenta, it follows that the final colours can be improved by reducing the amount of "magenta" which is printed wherever "cyan" is printed. Similarly, since the magenta image will be printed in a mixture of magenta and yellow, it follows that the final colours can be improved by reducing the amount of yellow wherever "magenta" is printed. Since the desirable reduction of the magenta image is at every point proportional to the printing strength of the cyan image and the desirable reduction of the yellow image is at every point proportional to the printing strength of the magenta image, the effect can be obtained by combining a positive image made from the red-filter negative with the green-filter negative, and a positive image made from the green-filter negative with the blue-filter negative. Clearly, the degree of colour correction obtained in this way is dependent on the relationships between the contrasts of the positive "masks" and the separation negatives. The greater the unwanted absorptions the greater must be the value—Density Range of Mask/Density Range of Negative. In practice it will be found that this value should be about one-fifth to one-quarter for the dyes used in

Autotype Tri-chrome Carbon Pigment Papers or in the Kodak Dye Transfer process but will have to be greater if less satisfactory colours are used.

Masking of this type will not result in perfect colour reproduction because it deals with only the major unwanted absorption in each of the two least satisfactory colours. Theoretically, at least two masks are required on each of the three negatives but the simple system suggested results in a major improvement without undue complications. It must be realized, however, that neither masking nor any other method of colour correction can give results as good as could be obtained if it were possible to make theoretically perfect colours. Obviously, no colour can be correctly reproduced in both hue and brightness if it is purer in colour than one of the printing colours. Imagine a colour which would be correctly reproduced by theoretical cyan and nothing else. Available imperfect cyan cannot reproduce the colour and it is not possible to reduce the magenta since none should enter into the synthesis in any case. A closer approximation to the correct hue might be achieved by printing some yellow with the imperfect cyan but the colour will then be a correct reproduction plus some grey. However, at the present time, masking gives the best colour reproduction possible by purely photographic means.

The masks should be made on a non-colour-sensitive material and developed in a low-energy developer which should give a fairly neutral coloured image. Diluted "fine-grain" developers of the metol-hydroquinone-borax type are suitable. The masks should be exposed by contact and care should be taken to use the straight-line portion of the characteristic curve of the mask material.

As two of the negatives are masked while the third is left unmasked, compensation for the difference in contrast has to be made at some stage. With some colour printing processes it is possible to adjust the contrasts quite easily but, in general, it is better to make the adjustment at the negative stage. For instance, if 20 per cent masks¹ are to be applied and the optimum negative density range for the printing process is 0.3 to 1.5 then the green- and blue-filter negatives could be developed to have a

¹ The percentage refers to the density range of the transparency to be corrected. Thus if the density range of the original is 1.0, a 20 per cent mask has a density range of 0.2.

25 per cent greater range, i.e. 0.3 to 1.8. Now the 20 per cent positive masks will have a density range of, say, 0.2 to 0.5 which when combined with the negatives will reduce their ranges to 0.8 to 2.0 thus balancing with the red-filter negative although at a higher density. Unfortunately, this method involves making one mask from the normal contrast red-filter negative and one from the high-contrast green-filter negative, and this is liable to lead to complications. All this may be avoided by making all three negatives to the higher density range and then making two positive masks from the red-filter negative and one from the green-filter negative. One of the red-filter masks is then combined with the red-filter negative thus reducing its density range without affecting its colour values. The other two masks are combined as before and the resulting set of combination negatives will be in balance both as regards contrast and overall density.

The masks should be registered carefully with the appropriate negatives and clipped to

them with bulldog clips on three sides. Gummed paper lantern slide binding strips should then be used to bind the negatives and masks together. The tape should be stuck on all four edges of the negatives, the bulldog clips being removed from each edge in turn. Plates are more convenient for both negatives and masks but films can be used, in which case it is advisable to trim the edges off the masks so that they are a little smaller all round than the negatives. Paper tape may then be stuck down flat to tape the two together.

Since the emulsion layers are sandwiched between the supports of the negatives and masks, it is necessary to print masked negatives by projection.

It is possible to calculate the correct value of masks required for a given set of printing colours but in practice it is not difficult to arrive at suitable values by trial and error. Once the value of masks required for a particular set of dyes has been determined the information may be used for as long as those dyes are in use.

CHAPTER LIII

THE PRACTICE OF COLOUR PHOTOGRAPHY BY CONTEMPORARY PROCESSES

1007. Introduction. It is obviously outside the scope of a single chapter in a book on photography in all its aspects to give working instructions for all the processes of colour photography considered in Chapter LI. Some practical information will therefore be given to enable the reader to attempt any of the processes which is readily available.

In colour photography by any process certain fundamental conditions apply. The choice of subject is important and, in general, the photographer should avoid the temptation to introduce colour for colour's sake. Except in very rare cases where special effects are required, the lighting for colour photography should be fairly "flat." For instance, for outdoor subjects sun obscured by light cloud is generally more suitable than brilliant sunlight. This is particularly true of transparency processes but it also applies to the making of separation negatives. There is no necessity for contrasty lighting as the colours themselves give interest which in monochrome work has often to be obtained by enhanced contrast.

Accuracy of exposure is essential and a high-quality photo-electric exposure meter or a photometer is virtually a necessity. For the transparency processes which involve reversal processing, the exposure accuracy necessary is of the same order as that required in printing on bromide paper. This is because the final positive image will be the complement of the negative image and the exposure must be such that the highest lights of the subject are recorded with a very low density. There is no opportunity to compensate for errors in the negative by adjustments in a printing process.

When separation negatives are made there is more exposure latitude but here there are three different exposures to determine for the three filters. It has often been stated that the use of correct filter factors is less important than developing the three negatives to equal contrast. This is true, however, only if the subject has a brightness range so short that all three records can be made on the straight line portion of the characteristic curve of the negative material even though, owing to the erroneous filter factors, the three records do not occupy the same position on the straight line. If the

range of the subject is such that the erroneous factors result in one negative being recorded on either the toe or the shoulder of the curve while another is on the straight line, serious colour errors in the final print are likely to occur. It is much safer to determine the filter factors with accuracy and this means that it is not sufficient to rely on the manufacturers' factors which are given merely as a guide based on the average product. Factors should be determined on each fresh batch of negative material under the lighting conditions to be used.

1008. In all colour work it is very important to avoid mixing light from different types of sources. For instance, no daylight should enter a studio where a colour photograph is being taken by tungsten illumination. Moreover, it is not desirable to vary the operating condition between the tungsten sources themselves. The common practice in monochrome work of using dimmers to lower the voltage on spot-lights should be avoided as this not only reduces the intensity of the light but also alters its colour. Intensity should, therefore, be varied by distance or by placing layers of muslin over the lights. Here, however, care must be taken that the muslin is bleached white or, again, the colour of the light will be changed. If these precautions are not observed there is a danger of introducing local falsification of colour values in the reproduction which can be most unpleasant.

Mercury vapour lighting is useless for normal colour photography as there is no red radiation from this type of light source. In general, fluorescent lighting is not satisfactory but it is likely that suitable lamps of this type will be introduced. Naturally, the various coloured sources of the neon or sodium type are not suitable. Daylight, white-flame arc-light, tungsten-light, over-run tungsten light, and flash-light can all be used with success provided that colour films are used with appropriate compensating filters or that suitable adjustments are made to filter factors for separation negatives.

TRANSPARENCY PROCESSES

The following processes are the only ones of the several so far mentioned that are available in Britain at the time of writing (1950).

1009. Dufaycolor. Dufaycolor Film is supplied in cut-sheet and roll-film forms. There are four types normally manufactured—

D.1. Roll Film, 35-mm Film for miniature cameras and sub-standard Ciné film. This type is intended primarily for amateur use.

D.2. Flat Film in cut sheets of normal contrast.

D.4. Flat Film "Process Medium." Higher contrast material recommended for photographing such subjects as oil paintings and certain types of medical subjects.

D.5. Flat Film "Process Hard." Material of high contrast intended for photographing such subjects as coloured maps and for photomicrography.

All these films require a correction filter to be placed over the camera lens. A filter, matched to the film, is supplied in each packet. Unless otherwise stated, this filter is for use in daylight but filters suitable for use in other types of light are available from the manufacturers.

Dufaycolor film must be exposed with its emulsion side away from the lens so that the exposing light passes through the réseau before reaching the emulsion (§ 986). Type D.1 roll films and cassettes are, of course, loaded by the makers in such a way that the exposure must be made from the correct side. Type D.2, D.4, and D.5 flat films must be loaded into the dark-slides so that the emulsion side is away from the lens. This should be done in total darkness as the emulsion is of the supersensitive panchromatic type. The films are packed in boxes of six with the emulsion all one way. A piece of black paper the same size as the film is attached to the emulsion side of each along one end. This should be left on as protection for the emulsion until immediately before development. Where film sheaths are used, the end of the film to which the paper is attached should be inserted first so as to carry the paper smoothly into the sheath with the film. The films may be loaded into plate holders by attaching them to glass plates with strips of adhesive tape. Alternatively, the films may be loaded behind clean glass plates, but, in this case, allowance must be made in focusing for the difference in focal plane. This can usually be done by turning over the focusing screen.

Exposures should be determined by means of a reliable photo-electric meter and a table of speed ratings for a large number of meters is issued by the manufacturers. For instance, the

film (with its filter) is rated as Weston 6 in daylight. Where no meter is available use can be made of the exposure tables also issued by the manufacturers.

1010. Processing. The processing procedure for all types of Dufaycolor film is the same and should present no difficulties to any photographer who is competent in monochrome processing.

The film should be developed in total darkness in one of the two developers given below—

DUFAYCOLOR DEVELOPERS

Developer A

Motol	.	.	.	3 g
Sodium sulphite (cryst.)	.	.	.	100 g
Hydroquinone	.	.	.	6 g
Potassium bromide	.	.	.	2.75 g
Ammonia (Sp. G. 880)	.	.	.	11 ml
Water to make	.	.	.	1000 ml

Developer B

Motol	.	.	.	6.5 g
Sodium sulphite (cryst.)	.	.	.	100 g
Hydroquinone	.	.	.	2 g
Sodium carbonate (cryst.)	.	.	.	100 g
Potassium bromide	.	.	.	2.75 g
Potassium thiocyanate (sulpho-	.	.	.	
cyanide) (pure)	.	.	.	9 g
Water to make	.	.	.	1000 ml

The development time at 65°F in Developer A is 3 minutes or in Developer B is 3½ minutes. Agitation during development should be vigorous. This is important as the brilliance of the final transparency is influenced considerably by the degree of agitation.

Development should be stopped in 1 per cent acetic acid and, after 1 minute in the stop bath, transferred to the bleaching bath which is made up as follows—

Potassium permanganate.	.	.	.	2 g
Ammonium persulphate	.	.	.	0.5 g
Sulphuric acid (conc.)	.	.	.	10 ml
Water to make	.	.	.	1 litre

The film should be bleached for 5 minutes with vigorous agitation. White light may be turned on after the film has been in the bleaching bath for 1 minute. After bleaching the film should be rinsed in water and transferred to a clearing bath made up as follows—

Potassium metabisulphite	.	.	.	25 g
Water to make	.	.	.	1 litre

After clearing it is possible, with a little practice, to judge the accuracy of the exposure and to take steps to compensate for slight under-exposure. The high-lights of the picture should appear almost black when the film is

laid face upwards on the bottom of a white dish and viewed by reflected light. If there is a veil over the high-lights the film may be bathed in a weak solution of potassium cyanide (0.1 per cent) until the veil is almost removed. Whether this treatment is given or not, the film is washed for 2 minutes in running water. The next step is to re-expose the film, from the emulsion side by holding it for about 30 seconds at 1 ft from a 100-watt lamp. It is desirable that there should be no drops of water on the emulsion during exposure.

Finally, the film is re-developed for 5 minutes in the first developer, fixed for 2 minutes, washed for about 15 minutes and dried. The full brilliance of the transparencies is not attained until they are dry.

Slightly thin transparencies can be improved by intensifying the silver image. Any method of intensification which does not seriously modify the neutral colour of the silver image can be used but some methods are a little risky. Probably the simplest and safest method is to bleach the silver in

Mercuric chloride	6 g
Potassium bromide	6 g
Water to make	250 ml

Bleaching takes 3 minutes after which the film is washed for 10 minutes and blackened in a 5 per cent solution of sodium sulphite, washed and dried.

Under-exposed transparencies which have not been reduced during processing may be reduced in Farmer's Reducer, but it is preferable to treat them at the earlier stage.

1011. Ilford Colour Film. Ilford Colour Film is at present supplied as 35-mm film for miniature cameras, in both daylight (Type D) and artificial light (Type A) emulsions (for photoflood). It is possible to use either of these films in alternative lighting to that for which they are balanced by the use of correction filters. This inevitably results in loss of speed. Both the daylight and the artificial light film have a speed of Weston 8.

The exposed film must be returned to the manufacturer for processing.

1012. Kodachrome. Kodachrome film is supplied in the form of 35-mm film for miniature cameras and as substandard ciné film. Both the miniature and substandard ciné films are supplied in the Daylight type and Type A for exposures by Photoflood light. Correction filters are available which enable good colour balance to be obtained when the films are exposed in

lighting other than that for which they are intended. Generally, it is preferable to use the correct film especially as maximum sensitivity is usually obtained in this way.

The film must be loaded in total darkness in such a way that it is exposed from the emulsion side. Exposures should be determined, where possible, with a photo-electric exposure meter. Speed ratings for use with various makes of meter and also an exposure table are obtainable from the manufacturers. As a guide to the speed of the material, the daylight film is rated at Weston 8.

It is not feasible for the photographer to undertake the processing of this material which must be returned to the maker for this purpose.

1013. Ektachrome. Ektachrome film is supplied in the form of cut sheets of two types; Daylight and Type B for exposures by Photoflood lighting. The film must be loaded in total darkness so that it is exposed from the emulsion side. The emulsion side is easily identified by the notches in the short edge of the film. When the notches are on the right of the top edge with the long side held vertically, the emulsion is facing the operator. As a guide to the sensitivity of the material, it is rated at Weston 6 to daylight.

Processing of the film demands unusual care but if the photographer is prepared to follow the manufacturer's instructions to the letter there is no reason why he should not be successful. Processing kits are available from the manufacturers of the film and these contain the necessary chemicals ready to be made up to 64 oz of each of five solutions. Full instructions are given with the kits so only an outline of the process is given here.

The solutions should be used as soon as possible after being made up and they should not be kept longer than 3 to 4 days at the most. The 64 oz of each solution is sufficient to process about 4 square feet of film with practically no change in colour balance or 5 square feet with sufficient accuracy for all but the most critical user.

Tanks should be used for processing because the emulsion on the film is easily damaged in dish processing and, moreover, it is a very much simpler proposition to control solution temperatures accurately in tanks. It is highly important that the first developer solution shall be used at a temperature of $68^{\circ}\text{F} \pm 0.5^{\circ}\text{F}$. Other solutions should be at between 66°F and 70°F . The temperature of the wash water should not

be outside the range of 65°F–72°F. The ideal method of achieving the necessary temperature control with convenience of operating is to have five half-plate developing tanks jacketed by a large galvanized iron tank filled with water at 68°F. Provided the room temperature is fairly near to 68°F the large volume of water will remain at a steady temperature for several hours. A washing tank will also be required and it is convenient to have a seventh tank for a solution of a wetting agent.

The five processing solutions are: (i) first developer, (ii) hardening bath, (iii) colour developer, (iv) clearing and fixing bath, and (v) bleaching bath. The total processing time is about 90 minutes and the first 19 minutes must be carried out in total darkness. The steps are as follows—

(a) *Develop* the film in total darkness in the first developer. The development time is 15 minutes at 68°F. Every 2 minutes the film should be lifted out of the solution, drained for 5 seconds from one corner and replaced. The film should be drained alternatively from the two bottom corners. At the end of the 15 minutes' development

(b) *Rinse* the film for 1 minute in running water at 65°F–72°F.

(c) *Harden* the film for 5 to 10 minutes at 66°–70°F. Withdraw the film every 2 minutes as described in step (a). After the film has been in the hardener for 3 minutes the room lights may be turned on and left on for the rest of the processing. The film should not be placed in the wash water before the reversal exposure.

(d) *Reversal Exposure*. The film should be exposed each side for 5 seconds to the light of a No. 1 Photoflood lamp placed 1 ft from the film. Alternatively, two Photoflood lamps may be positioned 2 ft apart and the film held between them for 5 seconds. These lamps get hot and will shatter if splashed with water. They should, therefore, be protected with sheets of plain glass placed to prevent splashing from the solutions or washing tank.

(e) *Wash* the film for 5 minutes in running water at 65°F–72°F.

(f) *Colour Development*. Develop the film for 25 minutes in the colour developer at 66°–70°F. Withdraw the film every 2 minutes as described in step a.

(g) *Wash* the film for 5 minutes in running water at 65°–72°F.

(h) *Clear* the film for 5 minutes in the clearing and fixing bath at 66°–70°F. Withdraw the film every 2 minutes as before.

(i) *Rinse* the film for 1 minute in running water at 65°–72°F.

(j) *Bleach* the silver image in the bleach for 10 minutes at 66°–70°F. Withdraw the film every 2 minutes as before.

(k) *Rinse* the film for 1 minute in running water at 65°–72°F.

(l) *Fix* the film in the clearing and fixing bath (the one used in Step (h)) at 66°–70°F. Withdraw the film every 2 minutes as before.

(m) *Wash* the film for 10 minutes in running water at 65°–72°F.

(n) *Remove water droplets* by bathing the film for 1 minute in a solution of wetting agent at 65°–72°F.

(o) *Dry* the film in a dust-free place. The film appears opalescent until it is dry.

PRINTMAKING PROCESSES

1014. The Trichrome Carbro Process. Bromide prints are made from a set of separation negatives and from these prints three Carbro prints are made as described in Chapter XLVI. A yellow pigment paper is used for the print from the blue-filter negative; a magenta paper is used for the print from the green-filter negative; and a blue-green pigment paper for the print from the red-filter negative. The pigment papers are sensitized, squeegeed on to their appropriate bromide prints and, when the bromide prints are fully bleached, are stripped off and mounted on waxed celluloid sheets for development in warm water. Finally, the three component images are transferred in register on to a single sheet of gelatine-coated paper either by the single or the double transfer method (§ 847).

Ordinary bromide papers have a supercoat of plain gelatine to render them less susceptible to stress marking. Such supercoated papers are not suitable for Carbro and it is necessary to use a paper specially made for the purpose. It is essential that all three prints are made on paper which has been cut the same way from the roll otherwise it will be impossible to obtain register between the three colour images. For this reason, paper should be purchased in the roll or in cut sheets packed specially for this process.

1015. Balancing the Bromides. If the separation negatives are in perfect balance the making of the bromide prints is relatively simple as it is necessary merely to determine correct exposure and development for a print from one of the negatives; prints from the other two will then

require identical treatment. In practice, however, it is usually necessary to make some slight adjustments to the exposures to compensate for minor inaccuracies in the negatives. In general, it is preferable to avoid printing from sets of separation negatives whose contrasts are unequal, but when this is unavoidable it is possible to use different developers to bring the prints to similar contrast or, in extreme cases, different grades of bromide paper (if available) may be used. Suitable developer formulae are as follows—

DEVELOPER FOR PRINTS FROM HARD NEGATIVES

Metol	8.5 g
Sodium sulphite, anhydrous	30 g
Sodium carbonate, anhydrous	37 g
Water to make	1 litre

Take developer 1 part, water 1 part. Develop for about 2 minutes at 65°F.

DEVELOPER FOR PRINTS FROM SOFT NEGATIVES

Hydroquinone	10 g
Metol	5 g
Sodium sulphite, anhydrous	36 g
Sodium carbonate, anhydrous	54 g
Potassium bromide	3 g
Water to make	1 litre

Take developer 1 part, water 2 parts. Develop for about 3 minutes at 65°F.

The wedge which should be recorded on the separation negatives (§ 997) should be included on the edge of the bromide prints. A test print should be made from one of the separation negatives so as to include a representative area of the picture and the wedge. When a print has been made which is judged to be correct, prints are made from the wedges on the other two negatives and the exposures and development times are adjusted until the three wedges match. Finally three prints are made from the three negatives using the exposure and development times determined from the test strips. The prints should be just sufficiently exposed to give full high-light detail when fully developed. The prints should be masked so that they have a clear margin at least $\frac{1}{4}$ in. wide all round. This is to avoid fixing when the Carbro prints are developed.

Fixing should be carried out very thoroughly in either plain hypo solution or in hypo with potassium metabisulphite. A hardening fixing bath should not be used. The prints should be washed very thoroughly and then bathed for 2 minutes in a 2 per cent solution of acetic acid and swabbed with cotton wool. A final

wash and drying of the prints completes this stage of the process.

1016. Three sheets of celluloid at least 4 in. larger each way than the print to be made are prepared by waxing the surface either with Autotype waxing compound or with a car polish of the "Karpol" or "Lifeguard" type. Celluloid is likely to be replaced for this purpose by other plastics such as "Perspex" which does not require waxing. The sheets should be about 1 mm thick for prints 12 in. \times 10 in. or larger or about $\frac{1}{2}$ mm thick for smaller prints.

The next stage is the production of the separate colour images on the celluloids. The three bromide prints should be soaked for 10 minutes in a buffer solution to bring them to pH 6.5. A satisfactory solution is made as follows—

Solution A.

Di-sodium hydrogen phosphate ($\text{Na}_2\text{HPO}_4 \cdot 12\text{H}_2\text{O}$)	24 g
Water to make	1 litre

Solution B.

Potassium di-hydrogen phosphate (KH_2PO_4)	9 g
Water to make	1 litre

For use take 100 ml solution B to 50 ml solution A. This solution can be diluted to 200 ml without change in pH.

The Autotype Company market two series of tri-chrome carbro pigment papers. Their "Series 2" papers are coated with pigments which have greater permanence but less brilliance than those used for "Series 3" papers.

1017. **Sensitizing the Pigment Papers.** The pigment papers may be sensitized either by the "Two-bath" or the "Single Bath" method. The single bath method requires the use of some mechanical aid for getting the sensitized paper into perfect contact with the bromide print quickly and evenly; it is certainly the better method where large sized prints or runs of prints from the same negatives are being made. The two bath method has usually been recommended to the beginner because it is rather more flexible and rather less costly in chemicals. It is hardly feasible to use mechanical squeegeeing methods in this case because the time of immersion in the second sensitizing bath is very critical.

Two-bath Sensitizing. Stock solutions are made as follows—

(A) Potassium ferricyanide	50 g
Potassium bromide	50 g
Distilled water to make	500 ml

(B) Potassium bichromate	. 18 g
Chromic acid	. 4 g
Chrome-alum	. 10 g
Distilled water to make	. 450 ml

The working baths are made up as follows—

No. I. Stock Solution A	1 part
Water	4 parts
No. II. Stock Solution B	1 part
Water	4 parts

The No. I bath may be used for a considerable number of prints but the No. II bath must be renewed after each set as it becomes contaminated with No. I bath. The temperature of the baths should not exceed 65°F and should preferably be 60°F. The pigment papers should be cut at least 1 in. longer each way than the bromide prints and a liberal quantity of the sensitizing solutions poured into two dishes.

Each of the three pigment papers in turn should be immersed for 2 minutes in the No. I bath, drained and squeegeed on to clean sheets of glass, stripped off and hung by clips from a line. They should be treated in the order cyan, magenta, yellow and, provided the room temperature is not above 65°F, there is no objection to completing the treatments in No. I bath before treating the cyan paper in the No. II bath.

1018. The cyan pigment paper is held taut along one of its longer sides and is drawn quickly and evenly under the surface of the No. II bath. The dish must be rocked throughout the treatment, the average time for which is 25 seconds. A shorter immersion time gives more contrasty, a longer time softer prints. The time taken to remove the pigment paper from the bath, position it on the bromide print and squeegee it down is, in effect, an extension of the time in the bath and is therefore very important. The operations must be carried out quickly, but it is even more important to carry them out in such a way that the time taken for each of the three prints can be kept constant. At the end of the chosen immersion time, the pigment paper should be removed from the bath, turned gelatine side downwards and one edge should be placed $\frac{1}{4}$ in. from the edge of the bromide print which should previously have been squeegeed face upwards on a sheet of glass and flooded with water. The pigment paper should then be evenly lowered on to the bromide print and immediately squeegeed down firmly, taking care that it does not slip.

The magenta and yellow pigment papers

are similarly treated in turn. As each squeegee operation is completed the pigment paper-bromide paper sandwich should be lifted from the glass and put between sheets of greaseproof paper in a cool place away from bright light.

After 10 minutes the cyan pigment paper is stripped from its bromide print, passed quickly through a dish of cold water, and squeegeed down on one of the waxed celluloid sheets. A sheet of grease-proof paper is placed over the paper and the celluloid is put aside for 10 minutes. The other two pigment papers are similarly treated after which the cyan print will be nearly ready for hot water development.

1019. **Single-bath Sensitizing.** In the single-bath process, control over contrast is achieved at the bromide print stage as there is no control stage in sensitizing. A typical sensitizing solution is made as follows—

Solution A

Potassium bichromate	. 10 g
Potassium ferricyanide	. 10 g
Potassium bromide	. 10 g
Distilled water	. 200 ml

Solution B

Glacial acetic acid	. 10 ml
Hydrochloric acid (pure)	. 10 ml
40 per cent formaldehyde	. 220 ml

To make the working solution take—

Solution A	. . . 10 ml
Solution B	. . . 1.25 ml
Water	. . . 70 ml

Add the B solution just before the pigment paper is immersed: the immersion time should be 3 minutes at 60°F.

The squeegeeing operation should be carried out with either a photographic or a domestic wringer. Two pieces of celluloid larger than the pigment paper should be hinged together along one edge with waterproof adhesive tape, and positioning marks should be painted on each side so that when the bromide print is positioned to the marks on one celluloid flap and the pigment paper is positioned to the marks on the other flap and the two flaps brought together, the two papers will come face to face in the correct position.

The celluloid folder is opened out on the bench and the wet bromide print is squeegeed face up in position on one flap. The pigment paper is removed from the sensitizing bath and squeegeed face up in position on the other flap. The hinged edge of the celluloid folder is now introduced into the wringer, taking care that

the two papers do not come into contact prematurely and the sandwich is wound quickly through the wringer. This ensures rapid contact between the papers without danger of slipping, provided that the wringer is properly adjusted. It is convenient to have three of the celluloid folders which can, of course, be used repeatedly. The complete sandwiches should be laid aside for 5 minutes and then the pigment papers should be stripped from the bromide prints and squeegeed on to the waxed celluloid sheets. The pigment papers should be left for 5 minutes on the celluloid sheets before commencing hot-water development.

1020. Development. A dish, about 3 in. longer each way than the celluloid sheets, is filled with water at about 105°F. The celluloid support bearing the cyan pigment paper is taken in both hands with the pigment paper underneath and is pressed firmly under the surface of the water so that the paper backing enters the water before the support. After a few seconds the support is turned over and is again completely submerged until pigment begins to ooze from the edges. The backing paper may now be stripped away and the remaining soluble gelatine gently washed away by shaking the celluloid laterally under the water. This washing is continued until no further colour runs off when the celluloid is lifted clear of the water and allowed to drain from one corner. The print is then given a rinse in cold water and placed to dry. The other two prints are similarly treated.

1021. Assembly of the Three Images. It is preferable to use the "Double Transfer" method in which the three component images are assembled on a sheet of Autotype "Soluble Temporary Support" and the assembly is finally transferred on to a final support. The temporary support paper should be very fully soaked and stretched to avoid difficulties with register due to dimensional changes in the paper after transferring has begun. The paper should be soaked for at least half an hour in water at 60°-70°F and then squeegeed vigorously, face down, on a sheet of glass. The paper should then be stripped off the glass and immersed face down in water at 70°-80°F until its gelatine coating feels slimy. The dry cyan image on its celluloid is then slid under the paper and the two are removed together and the paper is squeegeed down. The back of the paper is blotted and the sandwich is left to dry when the

paper will leave the celluloid taking the cyan image with it. Some of the wax will remain on the surface of the image and this must now be removed (this step is unnecessary if unwaxed Perspex has been used). The wax can be removed with certainty by swabbing over the surface with pure turpentine on cotton wool and then removing the turpentine with ether on soft lintless rag.

The paper bearing the cyan image is now soaked for 2 minutes in water at 70°F and turned face downwards. The celluloid sheet bearing the magenta image is slid underneath and the two are withdrawn together, slid into approximate register and lightly squeegeed into contact. The sandwich is placed, celluloid side upwards, on a sheet of blotting paper and the register is adjusted by pressure with the fingertips on the transparent support. The sandwich is then again left to dry and the magenta image is stripped from its celluloid. After de-waxing, the yellow image is transferred in the same way and its surface must also be de-waxed before the final transfer of the assembled print to its final support.

A sheet of Autotype "Single Transfer Paper" cut larger than the temporary support is soaked for 10 minutes in cold water. The assembled print on temporary support is soaked for not more than 1 minute and squeegeed into contact with the single transfer paper. The sandwich is left until it feels dry to the hand and is then immersed in a dish of water at 105°F. After a few minutes the temporary support is peeled off and a gentle laving of the surface of the print completes the operation. The print is finally hung up to dry.

1022. The Trichrome Carbon Process. Carbon prints are made in the appropriate colours by contact from separation negatives as described in (§§ 787-809). Autotype pigment papers series 1A are used for this process. The pigment papers are sensitized in a bichromate solution, dried and printed behind the negatives after which they are mounted for hot-water development on waxed celluloid (or other suitable transparent flexible support). The three component images are subsequently assembled on paper exactly as described for the Carbro process.

The sensitizing and drying procedure is the most exacting part of the process and this is discussed in detail in §§ 790-4. The only additional point which it is necessary to make here is the fact that the three differently coloured sheets

of pigment paper must be cut the same way out of their respective rolls in order to obtain register between the three images.

Accuracy in exposing the three prints is, of course, very important as slight inaccuracies will have a big effect on the final result. It is therefore desirable to use the most constant light source available and 400 watt high-pressure mercury-vapour lamps are highly recommended. If it is possible to stabilize the voltage applied to the lamp by means of a voltage stabilizing transformer, this will be found to be a great advantage. It is necessary to find the correct exposures for the three pigment papers by trial and error in the first place. This is best done by printing from a step wedge on the three pigment papers and adjusting the three exposures until a neutral grey image is obtained when the three are combined. This gives the exposure ratios which will be constant for the particular batch of pigment papers and for the chosen sensitizing conditions. Adjustments will, of course, have to be made to compensate for any variations in negative density. These adjustments can be made by calculation from density measurements if a densitometer is available.

The negatives must be masked round the edges to provide a "safe edge." When the pigment papers have been exposed they are transferred to sheets of waxed celluloid or other plastic such as "Perspex." The transferring must be carried out in artificial light away from the exposing lamp and is done by what is known as the "dry" method. The printed pigment paper is laid face down on one of the dry sheets of waxed celluloid and hinged to it by sticking a strip of waterproof adhesive tape along one edge. The celluloid is now fed between the rollers of a photographic or domestic wringer until the strip of tape is just gripped. The pigment paper is lifted away from the celluloid and a little water is poured on the celluloid, close to the rollers, from a narrow rubber tube or a spouted vessel while the wringer handle is turned to carry the celluloid through steadily. Water is fed continuously in the angle between the pigment paper and the celluloid until all the pigment paper has been rolled into contact. In this way all the surface of the gelatine is wetted just before it comes into contact with the celluloid while the paper base is hardly wetted at all.

1023. Development in warm water at 105°-110°F is carried out exactly as described for the Trichrome Carbro process, but, because the

backing paper is practically dry, the water takes considerably longer to penetrate and soften the soluble gelatine. This delay can be avoided by soaking the celluloid and pigment paper for 10 minutes in cold water before starting the warm-water development. The end point of the development process is not so sharply defined as in the Carbro process and the images will vary in density if the developing stage is not standardized. In particular, care should be taken not to allow the water temperature to exceed 110°F at any time and the agitation of the water should be kept as constant as possible.

If the separation negatives have been made laterally reversed the transfer of the three images to soluble temporary support and re-transfer to the final support should be carried out exactly as described for Trichrome Carbro. Since the final print by the carbon process is the same size as the negatives it is very often desirable to make duplicate enlarged separation negatives from the original negatives and the enlarging stage affords an opportunity for reversing the images.

If the separation negatives are not reversed it is necessary to use the single transfer process in which it is more difficult to see the register of the images in the order yellow, magenta, cyan, and in which the choice of support paper is limited to smooth surfaces. Soluble temporary support paper should be used for transferring the three images exactly as for double transfer except that the colours must be put down in the reverse order and the final combined print should be hardened by bathing in 5 per cent formalin solution for 2 minutes, rinsing in cold water and drying. The somewhat awkward step of registering the magenta image with the yellow is facilitated by carrying out the operation by the light of the high-pressure mercury-vapour exposing light. It is undesirable to expose the eyes to this light for long periods and a shield should be arranged to keep the direct rays from them.

1024. The Kodak Dye Transfer Process. Prints are made from separation negatives on three sheets of Dye Transfer Matrix Film, which is coated with an unhardened blue-sensitive silver emulsion containing a yellow dye. The images are developed in a tanning developer (§413) and the gelatine which remains untanned is washed out in warm water. This leaves three gelatine relief images on the films which are used to take up dyes

from a yellow, a magenta, and a cyan dye bath. After rinsing away any surplus dye the reliefs are squeezed in turn on to a sheet of paper coated with mordanted gelatine. The dye leaves the reliefs and is fixed by mordant in the single gelatine layer on the paper. The reliefs may be re-dyed and the dye transferred to paper, repeatedly.

The prints may be made by contact or by enlargement. In either case the exposures must be made through the film base so that the developed image is next to the base. The exposures must be adjusted to the maximum densities of the negatives. The tanning developer which is supplied packed ready for making up, is in three solutions. Use of "A" and "B" solution only gives matrices of correct thickness range from separation negatives having a density range of 1.1. Satisfactory matrices can be made from negatives of lower density range by replacing a proportion of the "A" solution by "C" solution thus—

Negative Density Range	Matrix A	Developer B	Solution C	Decrease Exposure by
1.10	75 ml	150 ml	—	—
1.0	70 ml	150 ml	5 ml	25 per cent
0.9	65 ml	150 ml	10 ml	33 per cent
0.8	50 ml	150 ml	25 ml	50 per cent

For each 10 in. × 8 in. film 225 ml of mixed developer should be used. Not more than 30 ml of "C" solution should be used in this quantity.

The processing of the matrices must be carried out systematically so that each of the three films receives the same treatment. It is desirable to develop them simultaneously in three dishes on a rocker so that they receive the same agitation. The appropriate quantities of "A," "B," and "C" solution are adjusted to 65°F in separate vessels, mixed together in a jug, poured into the dishes and the temperature is re-checked in each dish. Once the developer is mixed it oxidizes rapidly and it is therefore very important to waste as little time as possible getting it to correct temperature in the dishes. No more than 3 minutes should elapse between mixing the solutions and commencing development. The three films should be slid into the dishes at 15-second intervals so that each may be given exactly 3 minutes development. At the end of 3 minutes the developer should be rapidly poured off and replaced by a stop-bath of 5 per cent acetic

acid. The films should be agitated in the stop bath for 3 minutes. White light may be turned on after the last of the films has been in the stop bath for 30 seconds.

The films are transferred from the stop bath to the bottom of an upturned dish and washed for 2 minutes with a gentle spray of water at 130°–140°F. This removes the unhardened gelatine and the matrices are chilled for a few seconds in cold water and hung up to dry.

1025. The dry matrices are taped down with transparent cellulose tape in register on a sheet of glass. This is best done over an opal viewing table with a fairly powerful light. Two adjacent edges of the films are next trimmed off with a sharp knife or razor blade against a steel straight-edge. Care must be taken that the knife cuts squarely and cleanly through all three films. These registration and trimming operations should be carried out with great care as upon them depends the success of the semi-automatic registration method used to place the three matrices, in turn, on the mordanted paper. Time spent at this stage is well repaid because a series of prints in good register can be obtained from the matrices once they have been properly prepared.

The dyes are supplied ready for dissolving in distilled water. Ammonia and acetic acid must be added to each solution according to the instructions. The paper conditioning bath is supplied as a concentrated solution for dilution.

A sheet of dye transfer mordanted paper should be soaked for not less than 10 minutes and not more than 1 hour in the paper conditioning bath. The three matrices are rocked in dishes of the three dyes for at least 5 minutes.

1026. The dye transfer registration device is known as the register blanket and consists of a sheet of waterproof translucent plastic material which is hinged to the bench. A sheet of plate glass is let into the bench so that the blanket falls on to it. The underside of the blanket has thin discs of plastic cemented on it in such positions that the matrix films may be placed on the blanket so that their two trimmed edges come up against three of the discs arranged as an L. This gives positive three-point location so that when each film in turn is placed against the discs and the blanket is brought down into contact with the mordanted paper which has previously been located on the plate glass, their images fall in register. While

the matrices are dyeing, a piece of gelatine-coated paper the same size as the mordanted paper is soaked in water. The blanket is turned back on its hinge and the wet paper is slid on its under-side gelatine side outwards, so as to come up against three of the registration discs. The blanket is now rolled down into contact with the plate glass, using the special rubber-covered roller supplied. When the blanket is lifted again the paper will adhere to the glass and serve as a guide for positioning the mordanted paper for as many prints as are being made on that size of paper.

The sheet of mordanted paper which has now been soaking in the conditioning bath for the necessary 10 minutes, is removed from the bath and laid, gelatine side upwards, on the sheet of paper which was stuck down on the glass and squeezed down gently.

The matrix is now removed from the cyan dye bath, drained, slid into a dish of 1 per cent acetic acid (150 ml for a 10 in. \times 8 in.) and rocked for 1 minute. The acid rinse is poured off and the matrix is rinsed for a few seconds in a clean bath of 1 per cent acetic acid. The transfer blanket should now be turned back and the matrix placed on its underside, gelatine side outwards. The film is placed so that it can be slid into the position where its two trimmed edges come up against three of the locating discs on the blanket. The blanket is now rolled down by means of the roller and this brings the matrix into contact with the mordanted paper. After 4 minutes have elapsed, the magenta matrix should be removed from its dye bath and rinsed as described for the cyan matrix. At the end of this time the cyan matrix will have been in contact with the paper for 5 minutes and is removed by turning back the blanket and gently peeling the matrix off. The cyan matrix is placed in a dish of water and the magenta matrix is placed on the blanket and rolled down on the paper. This is repeated for the yellow matrix. When the yellow matrix has been in contact with the mordanted paper for 5 minutes it is stripped off and the complete print is peeled off from the underlying positioning paper which is left adhering to the glass. The print is preferably clipped to a sheet of thick cardboard or plywood and dried quickly in a warm draught.

The matrices should be bathed in a clearing bath to remove the last trace of dye from them and then washed for a few minutes in running water. They may then be dried and stored

for future use or immediately replaced in the dye baths to make the next print. The clearing bath is made as follows

Calgon	10 g
10 per cent Ammonia	3 ml
Water to make	1 litre

Although any major corrections in either density or contrast have to be made at the matrix-making stage of the process, some control is possible at the dyeing stage. The contrast of the transferred image from a given matrix may be increased slightly by increasing the strength of the first acid rinse bath and increasing the rinsing time. The contrast may be reduced considerably by adding from 1 to 10 ml of 5 per cent sodium acetate solution to 150 ml of first rinse bath and rinsing for between 1 and 5 minutes. Highlights may be cleared by adding from 0.25 to 5 ml of 5 per cent Calgon solution to 150 ml of first rinse bath.

1027. The Dufaytissue Process. This process is a modification of the Trichrome Carbon Process in which the three prints are made on celluloid films coated with pigmented gelatine. The "Dufaytissues" are similar to carbon pigment papers except that the base is non-inflammable film instead of paper; they require sensitizing before printing. The sensitizing bath is made up in two solutions as follows—

Solution A

Potassium (or Ammonium) dichromate	100 g
Water, distilled or boiled, to make	1 litre

Solution B

Glycerine	50 ml
Water, distilled or boiled, to make	100 ml

For use these solutions are mixed in varying proportions according to the contrast of the negatives from which it is desired to print. As in the normal carbon process, the higher the concentration of the dichromate in the sensitizing bath, the lower will be the contrast of the print. The volume of the B solution used should always be 2 per cent of the total volume, the proportion of the A solution being varied as required. As a guide, a suitable bath for making a print from high-contrast negatives would be solution A: 750 ml, solution B: 20 ml, water to make 1 litre; and a suitable bath for making a print from low-contrast negatives would be solution A: 300 ml, solution B: 20 ml, water to make 1 litre. The mixed solution deteriorates when stored and should be discarded when its colour darkens noticeably.

If the separation negatives are of equal contrast, the same sensitizing solution should be suitable for all three tissues but if the contrasts of the three negatives are unequal, the sensitizing baths must be adjusted to compensate for the inequalities.

The tissues should be cut at least 1 in. longer each way than the negatives and immersed in turn in the sensitizing solution face downwards for 3 minutes at a temperature of between 50° and 60°F (preferably 55°F). Care should be taken to wet the surface evenly and not to trap air bells underneath. The tissue should be handled as little as possible. At the end of the 3 minutes, the tissue should be withdrawn from the solution and squeegeed face down on to a sheet of clean glass. A strip of paper about an inch wide should be laid on the glass and the tissue positioned so that it overlaps the paper by about $\frac{1}{4}$ in. along one of its short edges. The tissue should now be lifted by the paper, stripped from the glass, and clipped, gelatine side outwards, on a sheet of plywood. The tissue, on its support, should be placed on a gentle current of air to dry. The air temperature should not exceed 70°F during the first half hour after which it may be increased to 80°F if desired. When the tissues are dry their celluloid sides should be polished with a dry cloth to remove the last traces of sensitizer. The sensitized tissues may be handled in ordinary artificial light.

The exposures are made through the celluloid base of the tissues. As in ordinary carbon printing, an opaque "safe-edge" should be provided on the negatives to avoid frilling on the prints. The cyan tissue is exposed by contact with the red-filter negative, the magenta tissue is exposed behind the green-filter negative, and the yellow tissue behind the blue-filter negative. The exposures should be made in the same way as described for the Trichrome Carbon Process. Dufaytissue is supplied in sizes which allow a $\frac{1}{4}$ in. wide safe edge all round the picture area and also a spare strip to be cut off the sensitized tissue for a trial exposure. As a guide to the exposure required, 5 minutes at 20 in. from a 400-watt high-pressure mercury-vapour lamp would be about correct, but test exposures should be made on each batch of sensitized tissue.

After exposure, the tissues are developed by placing them face upwards, in the bottom of dishes of warm water (110°F) for 3 minutes. After 3 minutes' development gentle agita-

tion should be given until all the soluble gelatine has been removed. When the test exposures are developed the time of development should be noted and the final prints should be developed for the same time. When development is complete the tissues should be rinsed in water at about 50°F and laid very gently on top of one another, in the order yellow, magenta, cyan, with their gelatine surfaces upwards, on a piece of the gelatine-coated paper that is to be used for the final support. This allows the balance of the final print to be judged and, if any of the colours are found to be too dark, it can be reduced slightly by further development in water at 115°F followed by a cold rinse. The images are very delicate at this stage and registration of the three tissues should be adjusted with as little sliding about as possible. When the balance is judged to be satisfactory the tissues should be given a final rinse in a wetting agent and hung up by one corner to dry in a current of air at not more than 80°F. All the images should be the same way up.

1028. The images are transferred to gelatine-coated paper in the order yellow, magenta, cyan. The dry paper should be laid down gelatine side upwards on a flat glass surface and secured by its corners with waterproof self-adhesive tape. The yellow tissue should now be laid face downwards in position on the paper and secured along one of its short edges with a strip of self-adhesive tape. The tissue is then lifted and Dufaytissue gelatine adhesive solution is run in a narrow line into the angle formed between the tissue and the paper. The tissue should be allowed to fall back into place and squeegeed down with a single, firm stroke with a flat squeegee. The stroke should be away from the tape hinge so that the adhesive is rolled out and the tissue is stuck to the paper all over. The sandwich should be hung up to dry at room temperature so that the image is the same way up as before. When drying is complete it will be found that the celluloid can be peeled off leaving the yellow image on the paper. The paper should now be replaced on the glass, taped down as before, the dry magenta tissue registered on the yellow image and a sheet of glass smaller than the tissue placed on top to keep it in position. A strip of adhesive tape is stuck along one of the long edges of the tissue to hinge it to the paper. The tissue should then be lifted, adhesive poured in, and the tissue squeegeed down. After drying again the celluloid may be peeled off and the

cyan image registered and transferred in the same way. The assembled print is finally hardened by soaking for 10 minutes in 5 per cent formaline solution, washed for 10 minutes and dried.

1029. The Wet Carbon Trichrome Process. The wet carbon process is very similar to the normal carbon process except that the pigment papers are exposed while they are still wet from the bichromate sensitizing bath. This method gives prints of fair quality and is useful for obtaining proof prints from sets of separation negatives.

The special wet-printing pigment papers (Autotype Series 4) are sensitized for about 2 minutes at 60°F and squeegeed on to three sheets of thin waxed cellulose nitrate (0.003 in. thick). The backing papers are blotted off with an absorbent pad and the faces of the celluloids are polished. The three pigment papers are then exposed by contact behind their appropriate separation negatives through the celluloid supports. After exposure, the sandwiches are placed in warm water and developed as in the carbon process. Finally, the three component images are assembled by transfer in register to a sheet of gelatine coated paper.

Sensitizing should be carried out exactly as described for the carbon process except that a sheet of the waxed celluloid should be immersed with the pigment paper in the bichromate solution. After 2 minutes, the two should be removed together and squeegeed together with the gelatine side of the pigment paper in contact with the waxed side of the celluloid. The face of the celluloid should be polished thoroughly but gently so as to avoid bruising the swollen gelatine on the other side. The sandwiches should be left in a cool, dark place for five to ten minutes before being placed in the printing frame.

The celluloid side of the sandwiches should be placed in contact with the negatives and sheets of celluloid, glass, or undamaged waxed paper should be placed at the backs of the pigment papers to prevent evaporation during printing. The printing frame must not get warm during printing and, if necessary, a fan should be used to blow air over the glass. Uniform "flash" exposures in addition to the exposures behind the negatives will assist in retaining delicate high-light detail. A uniform exposure of 5 seconds at 18 in. from a 400-watt high-pressure mercury-vapour lamp will have this effect without fogging the whites.

The celluloids should be removed from the printing frame and placed in water at 90°F and the backing papers peeled off as soon as they will come away readily and before bubbles are formed between the gelatine and the celluloid. Development should not be commenced at higher temperatures otherwise the delicate tones of the image will be mottled. The temperature of the water should be raised gradually to 105°F and development taken to completion.

The three prints should be chilled in cold water and may then be assembled wet in register on a white surface to check colour balance. If necessary, the density of any of the images may be reduced by further development in slightly warmer water. There is a limit to the corrections which can be made in this way and the best results can only be obtained by correct exposure. When the temporarily assembled prints are judged to be satisfactory they should be separated and hung up to dry. The images can now be picked up on a soluble temporary support in the order yellow, magenta, cyan and treated exactly as described for Trichrome Carbon.

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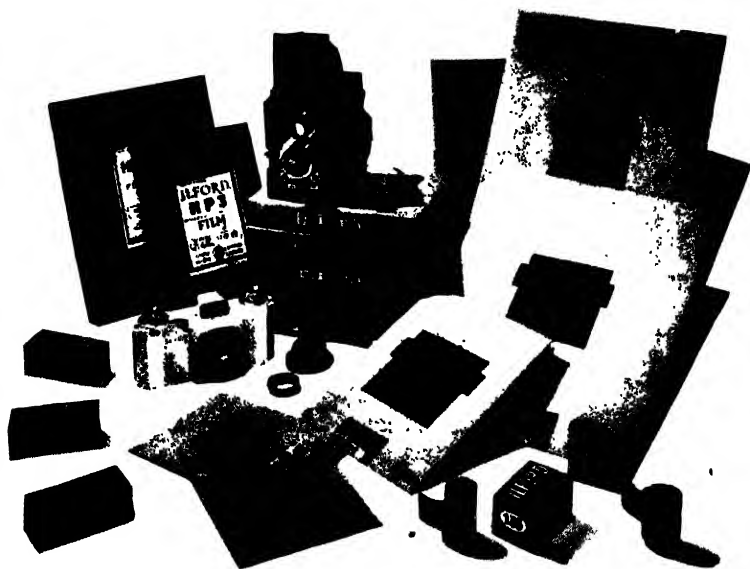
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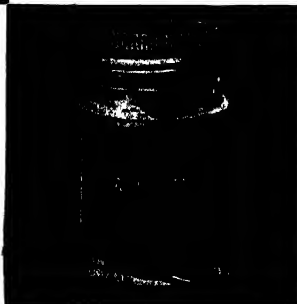
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